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THE KINEMATICS OF MACHINERY.

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LECTURE I.

MOST of the models used to illustrate this and the following lecture belong to the Kinematic Collection of the Gewerbe-Akademie in Berlin, and have been designed by Professor Reuleaux, who is the Director of the Academy and a Professor in it. The rest were sent to the Loan Collection by Messrs. Hoff and Voigt of Berlin, and Messrs. Bock and Handrick of Dresden. In essentials there is no difference between the Berlin and the Dresden models. Both have been designed specially for use in instruction in the Kinematics of machinery.

I must first try to explain briefly, but exactly, what I mean by the phrase "Kinematics of machinery." Professor Reuleaux, whose models are before us, defines a machine as "a combination of resistant bodies so arranged that by their means the mechanical forces of nature can be compelled to do work accompanied by certain determinate motions." The complete course of machine instruction followed in some of the Continental technical schools covers something like the following ground:

First, there is the perfectly general study of machinery, technologically and teleologically. Then there comes what we may call the study of prime movers, which in terms of our definition would be the study of *the arrangements by means of which the natural forces can be best compelled to do the required work.* Then comes the study of what may be called "direct actors," or the direct-acting parts of machinery; in the terms of our definition, *the arrangement of the parts of a machine in such a way as best to obtain the required result.* Next comes what we call machine design; the giving to the bodies forming the machine the requisite quality of resistance. Machine design is based principally on a study of the strength of materials.

One clause of the definition still remains untouched. The machine, we said, does work *accompanied by certain determinate motions.* Corresponding to this we have in machine instruction the *study of those arrangements in the machine by which the mutual motions of its parts, considered as changes of position only, are determined.* The limitation here must be remembered; motion is considered only as a change of position, not taking into account either force or velocity. This is what Professor Willis long ago called the "science of pure mechanism," what Rankine has called the "geometry of machinery," what Reuleaux calls "kinematics," and what I mean now by the "kinematics of machinery."

The results of many years' work of Reuleaux in connection with this subject are embodied in his book *Die Theoret-*

* Abstract of lectures delivered at South Kensington.

ische Kinematik, which I recently had the pleasure of translating, and I shall endeavor to give you an outline of his treatment of the subject. It cannot be more than an outline, as you will readily understand. The subject is a very large one, and I have had to choose between taking up many braches of it and merely mentioning each, and confining myself to a few points, and going more into detail about them. I have chosen the latter plan, believing that the former would be of little benefit to anybody. It will be easy for those who are sufficiently interested in the matter to follow it up, and to study those parts which I omit, by the aid of the book I have just mentioned. My lecture to-day will be principally theoretical, and to-morrow I shall go more into practical applications. So far as possible, as I have Professor Reuleaux's models before me, I shall endeavor to follow his own order in treating the subject.

I presume you are acquainted, to a certain extent, with the ordinary method of studying "pure mechanism;" the method originated by Monge (1806), developed in Willis' well-known *Principles of Mechanism* (1841), and made popular, to a great extent, by Prof. Goodeve's capital little text book and others. Each mechanism is studied for and by itself, in general, by the aid of simple algebraic or trigonometric methods, and is spoken of in reference to a certain "conversion" of motion which occurs in it. Thus, we have the conversion of circular into reciprocating motion, the conversion of reciprocating into circular, &c., and simple formulæ express certain relations between the motions of two or more moving points. In this way we know something important about a great number of mechanisms, and arrive at many results which are both useful and interesting. Some things are still left wanting, however; and these things may be summed up in this way:

(1.) We notice at once that we have taken the mechanism as a whole. We do not *analyze* it in any way whatever, and therefore,

(2) We have scarcely any knowledge of its relations with other mechanisms, or (what is quite as important) of the various forms which one and the same mechanism may take. We shall see presently how extraordinarily various these forms are. We have never a *general* case with special cases derived from it; each case is treated by itself as a special one. Then

(3) The mechanism is studied in general from a point of view which gives us only the conditions of the motion of two points in it, or two portions of it, and is then left. The kinematic conditions of the mechanism *as a whole* remain absolutely untouched.

In such a mechanism as that of an ordinary steam engine, for instance, we study the relative motions of the guide block and the crank, or, I ought, perhaps, to say of the axes of the crosshead and of the crank pin. We thus know the motions of two points in the rod which connects those axes, the "connecting rod," but we leave the motions of its other points untouched. It may, of course, be said that these others are of much less practical importance. This is true to some extent, although their practical importance is greater than might be supposed at first. But in any case these motions must certainly be studied if we are to obtain a *complete* knowledge of the mechanism to which they belong. Any method of study, therefore, which covers all the kinematic conditions of the mechanism, instead of the mechanical conditions of two or three points only, possesses in that respect very great advantages.

The treatment of mechanisms which I shall sketch to you, is intended to remedy some of the defects which I have enumerated. Those of you who have studied modern geometry, side by side with the old methods, will recognize that these defects are somewhat analogous to those of Euclidean geometry. The attempt to remedy them proceeds in lines similar to those of modern geometry, and will eventually, I believe, when more fully worked out, take the same position in its own subject.

Let us, then, look first at the *analysis of mechanisms*. This is none the less important a matter that its results are so very simple in many cases. A clear understanding of those elementary matters is of great assistance in clearing up difficulties which occur in the more advanced parts of the subject.

In a machine or a mechanism of any

kind *the motion of every piece must be absolutely determinate at every instant.* It will be remembered that we are at present considering motion as *change of position* only, not in reference to *velocity*. The motion of change of position *may* be determined by the direction and magnitude of all the external forces which act on the body; the motion is then said to be *free*, but it is obviously impossible to arrange such a condition of things in a machine. The motions may, however, be made absolutely determinate independently of the direction and magnitude of external forces; and in order that this may be the case, the moving bodies, or the moving and fixed bodies as the case may be, must be connected by *suitable geometric forms*. Motion, under these circumstances, is called *constrained* motion.*

If I allow a prismatic block to slide down the surface of an inclined plane its motion will be free; it is determined by the combination of external forces which act upon the block. If the block be pressed on one side as it slides, it at once moves sideways, and can only be kept in a straight path if directly the pressure is exerted on the one side an equal and opposite force (or a force which has a resultant with the first in the direction of motion), be caused to act upon it on the other. If, on the other hand, the block be made to slide between accurately-fitting grooves (like a guide block in a machine), inclined at the same angle as the plane, and like it fixed, the block may be pressed sideways or in any other direction, but no alteration in its motion can take place; the motion is "constrained," it can occur only in the one direction permitted by the guiding grooves. In the one case the external force has to be balanced by another external force; in the other the balancing force is molecular, *i. e.*, is a *stress* and not an external force, and comes at once into play the instant the disturbing force is exerted. The geometric forms which are used in this way to constrain or render determinate the motions in machines are very various, and are chosen in reference to the particular motion required. If every point in a body be required to move in a circle about some fixed axis, a portion of the body is made in the form of a solid of revolution about that axis, and this is caused to "work in" another similar solid; the two forming the familiar pin and eye. If all points of a body be required to move in parallel straight lines we get similarly for guiding forms a pair of prisms of arbitrary cross section; a slot and block. If every point of a body be required to move in a helix of the same pitch we use a pair of screws of that pitch, one solid and one open, for constraining the motion—a screw and nut.

The *general* condition common to these very simple forms is that, in each case, *the path of every point in the moving body is absolutely determined at every instant*, that is to say, the change of position of the moving body is absolutely determinate.

The geometric name for these mutually constraining bodies is *envelopes*, and each one is said to envelope the other. We shall call them (kinematic) *elements*, and the combination of two of them we shall call *a pair of elements*.

Those we have mentioned are special and very familiar and important cases of pairs of elements, which are of great simplicity. They have the common property of surface contact, the one enclosing the other, and are therefore called *closed* or lower pairs of elements. They are, moreover, the only closed pairs which exist. They are, further, the only pairs in which all points of the moving element have *similar* pairs.

Every point of an eye, for instance, moves in a circle about the same axis. If there were attached to it a body of any size or form whatever, all its point would move about the same axis. The "point paths" would all be concentric circles. Again, whatever the external size or shape of a nut, every point in it moves in a helix of the same pitch about the axis of the screw; the point paths, that is, would be similar.

The general condition of determinateness of motion can, however, be fulfilled by an immense number of other pairs of elements. The theory of these is too large a subject to be entered into just now, I must merely direct your attention to the existence of such combinations.

* Essentially it does not differ from free motion; the difference really lies in the substitution of *stresses* or *molecular forces*, which are under our complete control, for external forces.

Fig. 1 represents one of the simplest that can be used. Here one of the elements is an equilateral triangle, ABC, the other is the "duangle" RPSQ.

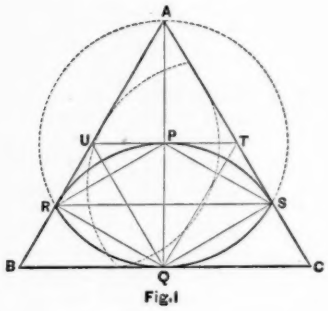


Fig. 1

The latter moves within the former, touching it always in three points, or rather along three lines. Its motion is just as absolutely determinate as the motion of a pin in an eye. It is free to move at any instant only about the point in which the three normals to the triangle at the points of contact intersect (as Q in the Fig.). The models before you show a few of the many forms taken by such pairs of elements. It is worth while noticing a few points in which the motions determined by them differ from the motions of the closed pairs. First, as we have already seen, the contact of the elements determining the motion was surface contact in the former case, while here it takes place only along a finite number of lines. Then the motions of all points in the first case were similar; in these pairs the motions of the points are not similar, but entirely dissimilar, the motion of each point depending entirely upon its position. Fig. 2 shows a few of the point paths of the pair of elements shown in Fig. 1. The strikingly different curves obtained from one pair of elements, according to the choice of the describing point, is too obvious to need further notice.*

These pairs of elements are called *higher pairs.* They have only a few applications in practice, their interest being chiefly theoretical. From our present point of view their theoretic interest is considerable, because of their exact analogy with the lower pairs.

There is another difference between the two kinds of pairs which deserves notice, for reasons which will be better

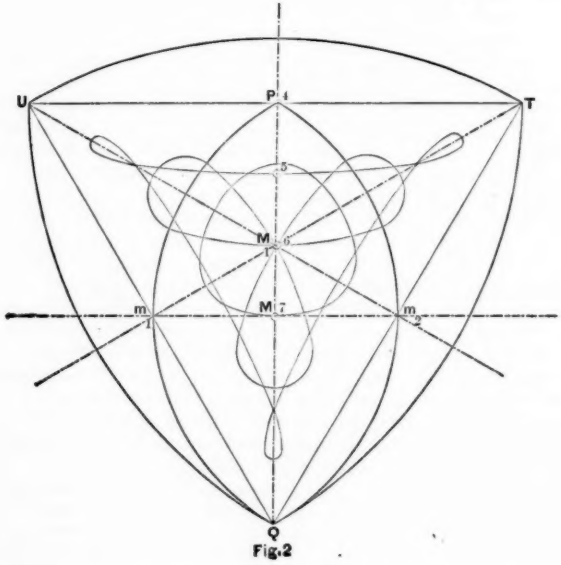


Fig. 2

understood afterwards. The pair of elements determine the relative motion of the two bodies connected by them. If one body be stationary on the floor or the earth, the moving body has the same motion relatively to the floor or earth that it has to the other element. If I move about both bodies in my hand, both have motion relatively to the earth, but the relative motion of the one to the other remains unchanged. It is of course only a case differing in *degree* from the former one. for in the former one both bodies had the motion of the earth itself, while one had the additional motion which I gave it. We may, however, not to be pedantic, speak of anything as "fixed," or "stationary" which has the same motion as the earth.

Now, (in this sense) we may *fix* either element of a pair, and with the lower pairs the *relative motion taking place remains the same* whichever element be fixed. With the higher pairs, on the other hand, the relative motion is altered, and the point paths become entirely different. The point paths of the duangle relatively to the triangle are, for instance, quite different from those of the triangle relatively to the duangle. This change of the fixed element is called the *inversion* of a pair.

The ultimate result of our analysis of mechanisms is then pairs of elements; we cannot go below this. The pairs we have noticed are of two kinds, each having their own definite characteristics. If, now, two or more elements of as many different pairs be joined together we get a combination which is called a (kinematic) *link*. It is obvious that the form of such a link is, kinematically, absolutely indifferent. The choice of its form and material belongs to machine design. It may be brick and mortar, cast iron, timber, as we shall see afterwards, but the fact that this is indifferent, kinematically, cannot be too distinctly kept in mind.

We can make combinations of links by pairing the elements which each contain to partner elements in other links, and such combinations are called *kinematic chains*. Thus, if we denote similar elements by similar letters, *aa*, *bb*, *cc*, &c, and the link connection by a line, we may indicate some of the chains obtainable from 4 pairs and four links, thus;

$$a \text{——} bb \text{——} cc \text{——} dd \text{——} a$$

(we suppose the "chain" to return on itself and the two elements *a* to be paired, the whole forming a *closed chain*); or,

$$a \text{——} cc \text{——} bb \text{——} dd \text{——} a$$

or

$$a \text{——} dd \text{——} cc \text{——} bb \text{——} a \text{ \&c.}$$

For the sake of illustration we give in Fig. 3 a sketch of a familiar chain containing four links, each connected to the

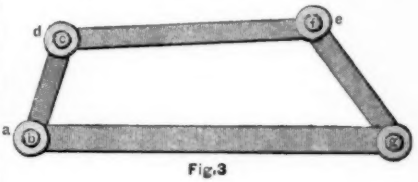


Fig. 3

adjacent link by a cylinder pair of elements. The axes of the four pairs of elements are parallel.

We have, then, in the kinematic chain, a combination so constructed that all its parts have determinate motions, motions absolutely fixed by the form of the elements carried by its links, and independent (considered as changes of position) of the application of external force. To convert the chain into a *mechanism* we have only to do what we have already done in connection with pairs of elements, fix one element—or, as each element is rigidly connected with a link, we may say preferably *fix one link*. Any link may be fixed, the chain, therefore, gives us as many mechanisms as it has links. In general these are different, in special cases only two or more of them are the same. We shall be able to enter into this part of our subject at some length in the next lecture; at present it will suffice to note two or three of the leading characteristics of chains and mechanisms which we can now easily recognize. These are,

(i.) That the motion of any link relative to either adjacent link is determined by the pair of elements connecting them.

* The triangle UTQ and the three curves within it, which have M_1 for their center, are point paths. The curve triangle and the duangle shown in thicker lines will be explained further on.

(ii.) That the motion of any link relative to any other than its adjacent links depends on *all* the elements of the chain.

(iii.) That no link of a *mechanism* can be moved without moving all the other links except the fixed one, and

(iv.) That there can be only *one* fixed link in a mechanism.

The two last propositions require a few words of explanation. Suppose that in any combination, of, say, four links, two can be moved without moving the other two, the combination is actually one of three links only, for clearly the two immovable links may be made into one, and are two only in name. This is very often the case in machinery, where special mechanisms are frequently used for the express purpose of connecting rigidly two or more links, and making them act as one, at certain intervals.

If, however, in the combination supposed, one link be fixed, while two can be moved and the fourth can *either* move or be stationary, the combination no longer comes under our definition of *constrainment*, for the motions are at a certain point indeterminate, at the point, namely, when it is possible for the fourth link either to move or to stand. Chains often occur in which this would be the case were it not that mechanicians take means, either by adding other chains or in other ways, to constrain the motion which would otherwise be useless to them.

We have now obtained some idea of the way in which mechanisms are formed, of the elements of which they consist. Before applying the knowledge we have thus acquired I must direct your attention to some geometric propositions which will greatly facilitate the theoretic dealing with these mechanisms.

In order that I may not enter into too wide a subject, I shall confine myself here to the consideration only of "conplane" motions, or motions in which all points of the moving body move in the same plane or in parallel planes. The limitation is a large one, but the cases included under conplane motion cover the greater part of those which occur in practice. The method which I have to describe is equally applicable to general motion in space as to simple constrained conplane motions of which I shall speak.

Let me remind you that the motion of any *figure* moving in a plane is known if the motion of any two points (*i. e.* of a line) in it be known. The motion of any *body* having conplane motion is known if the motion of a plane section of it, parallel to the plane of motion, be known. Such a plane section of it is, of course, simply a plane figure moving in its own plane. The motion of any *body* having conplane motion (as in nine cases out of ten in machinery), can therefore be determined by the determination of the motion of two points. In speaking now, therefore, of the motion of a *line* for shortness' sake, it must be remembered that we are really covering all cases of conplane motion of *solid bodies*.

In Fig. 4 PQ and P_1Q_1 are two positions of the same plane figure, or plane section of a body having conplane motion. If now we have two positions (in the same plane) of any plane figure, we know that the figure can always be moved from the one to the other by turning about some point in the plane. The position of the point O, about which the figure can be turned from the position PQ to the position P_1Q_1 can be found at once by the intersection of the normal bisectors to PP_1 and QQ_1. The motion of PQ in the plane is, of course, its motion relatively to the plane, and therefore relatively to any figure (as A B) in the plane. Such a point O as we have found here is called a *temporary center*, because the turning or motion takes place about it for some finite interval of time. It will be remembered that not only the two points and PQ of the figure, but every other point of it, must have a movement about this same point O at the same time. Now suppose we have some further position of the same figure, as for example at the position marked P_2Q_2, we can find in the same way the center about which the figure must be turned to move from P_1Q_1 to P_2Q_2. We may indicate this point as O_1. Similarly taking other positions of this figure P_3Q_3 and so on, we can find other points, O_2O_3, &c. By joining the points $OO_1O_2O_3$, we obtain a polygon, and if the figure in its motion come back to its original position the polygon also comes back on itself, and passes again through the point O. Such a polygon, whether it be closed in this way or not, is called a *central poly-*

gon; its corners are the temporary centers of the motion of the figure.

I have pointed out that all the points in the figure PQ move round O during the motion from PQ to P_1Q_1. They move round O necessarily through some particular angle, the angle POP_1, and every point moves through the same angle, which we may call φ_1. As the figure may have any form we choose, let us suppose it so extended as to contain a line which is the same length as OO_1, and which makes with OO_1 the angle φ_1, that is to say, the angle through which

These polygons have important properties, the principal of which can be very easily recognized. The first polygon does not alter its position during the motion of the body; it is therefore fixed, so that it may be considered *as a part of any figure such as* AB, which is fixed or stationary in the plane of motion. The second polygon moves with PQ *and forms* (by construction) *part of the same figure with* PQ. This second polygon then, by the consecutive turnings of its corners upon the corresponding corners of the first (and equal-sided) polygon,

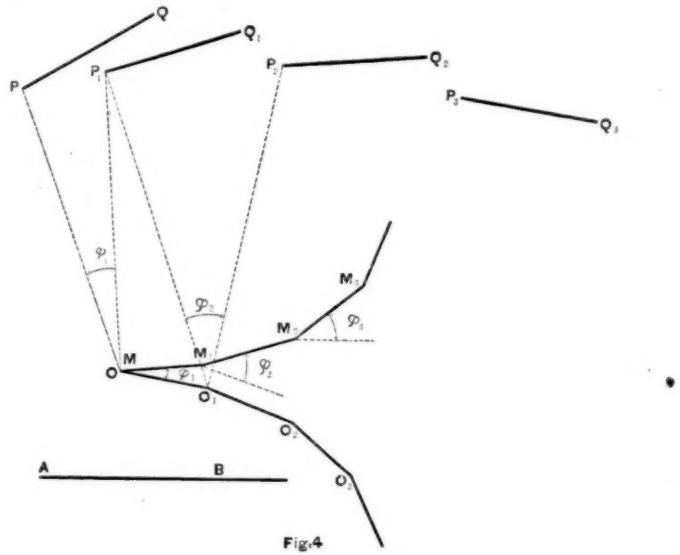


Fig. 4

the figure moves about O. Such a line is shown in Fig. 4 by MM_1.

We have, then, a line MM_1 forming a part of the figure PQ, equal in length to OO_1, the points O and M coinciding, and the angle O_1MM_2 being $=\varphi_1$. Then when the figure has completed its motion about O, MM_1 and OO_1 must coincide. Take further similarly $M_1M_2=O_1O_2$ and so placed that when M_1 coincides with O_1, $< O_2M_1M^6=\varphi_2$, then when the figure takes its third position, completing the turning about O_1, M_1M_2 coincides with O_1O_2. Similarly we can obtain M_2M_3, &c. The figure thus found is another polygon, which we may call a *second central polygon.*

will give to PQ the required changes of position relatively to the fixed plane or to the figure AB lying in it.

If, therefore, we know the central polygons for the given motion, we know not only the changes of position of the points P and Q, but those of every other point connected with the moving figure, whatever form it may have. For at any one instant every point in the figure is moving about the same center. In studying the relative motions of the figures we may, therefore, quite leave out of sight their *form* if we only know the central polygons for the motion. These tell us, so far, all about the motion which is taking place.

We may go further, however. We have recognized the fact that the relative motion of two figures or bodies may take place equally whether one or the other of them be fixed, or both moving. In the case before us we have supposed AB fixed and PQ moving relatively to it. The second polygon then moves on the first, and expresses the relative motion taking place. If, however, we suppose PQ fixed and AB moving, then the polygons still express the relative motion; but the second is now fixed and the first rolls upon it. This follows directly from the constitution of the polygons. The properties of the polygons as expressing "infinitely small parts of equal length continually fall together after infinitely small rotations about their end points." In other words the two curves *roll* on one another during the continuous alterations in the relative position of the two figures. Instead of finding points now by the intersection of normal bisectors, they are found by intersection of *normals to the paths* of P and Q (Fig. 5). The turning about each point now occurs (not in general) for a finite period, but for *an instant* only. Each point is therefore called an *instantaneous center*. The curve containing all the instantaneous centers, or the *locus* of instantaneous

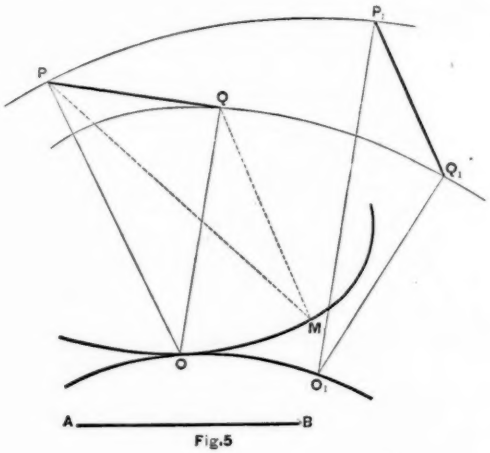


Fig.5

the relative motions of the bodies to which they belong are, therefore, reciprocal.

You will have noticed, no doubt, that the polygons do not express *continuous motion*. They define only a series of changes of position in their beginning and end, not telling us of the intermediate stages.

We may, however, take the consecutive position of the figures *as close together as we like*. The closer together they are taken the shorter become the sides of the polygons. If at last the distances PP_1, P_1P_2, QQ_1, &c., be taken *infinitely small*, each corner of the polygon will be *infinitely close* to the next one. That is to say the two polygons will become *curves*, and of these curves centers, is called a *centroid*. Without giving them any special name, several writers on Mechanics have made more or less use of these curves. Among these I may mention Dwelshauvers-Dery, Schell and Pröll. Reuleaux has, however, given them a name (*Polbahnen*), and has made some special use of them, more, I think, than has been made by former writers.

While the polygons only represent a series of isolated positions of a body, the centroids, rolling on each other, represent the whole motion continuously. Like the central polygons their properties are reciprocal. If then the centroids of two figures be known, their relative motions for a series of changes of position, each infinitely small, are also known,

i. e. their motions are *completely* determined.

If AB and its centroid be fixed, and the centroid of PQ rolled upon it (Fig. 5), we have now the means of determining the path of motion of every point in the Fig. PQ relative to AB, whatever may be the form of PQ. It is sometimes of great convenience to be able to find the motions of all points in a body in such a very simple way. Reciprocally we can determine the point paths of A B relatively to PQ, which, in general, differ entirely from those of PQ relatively to AB.

If *both* figures be moving, as frequently happens in practice, both centroids are also in motion; their motion relative to each other, however, remains unaltered. They still roll on one another, and their point of contact is still the instantaneous center of the motion of each relatively to the other. Each figure moves, relatively to the other, about this point, which being common to the two centroids, is common to the two figures. They might, therefore, for the instant, be connected at that point by a cylindric pair of elements. There are many problems of which the solution is greatly simplified by the recollection of this fact. The point in each figure which coincides with the instantaneous center, has, therefore, no motion relatively to the other figure. We have already seen this in the special case where the one figure is stationary, for then the point in which the moving centroid touches the fixed one is, by hypothesis, also stationary for the instant; in other words, it has no motion relatively to the fixed centroid. We now see the general condition of which this is a special case.

Fig. 6 shows the centroids for the higher pair of elements of Fig. 1. The curve triangle UTQ is the centroid of the triangle ABC, and the shaded duangle PVQW is the centroid of the duangle RPSQ.* As the duangle moves in the triangle (the elements *sliding* upon each other), its centroid *rolls* within the centroid of the triangle. Both centroids are in this case formed of arcs of circles, and all the point paths (being determined by the rolling of one circular arc upon another) are combinations of trochoidal arcs.

The centroids of kinematic chains are generally of greater complexity than those of the pairs of elements just mentioned, but in some cases are quite as simple. In Fig. 7, for example, is shown a mechanism familiar to engineers, in which a crank a drives a reciprocating bar c by means of a block b working in a slot. The centroids defining the relative motions of the links a and c are the two circles shown in full lines, one double the diameter of the other. These two circles both move as the mechanism works (supposing the link d to be fixed), but always so that they roll continuously one on the other. If instead of fixing d the crank a were made the fixed link, the same centroids would still express the relative motions of a and c. The smaller circle, the centroid of a, would be stationary along with the link to which it belongs, and the other would roll on it, the instantaneous center for the motion

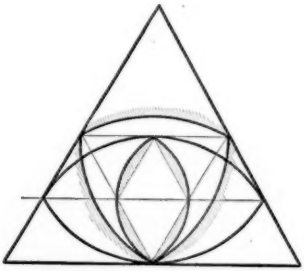


Fig. 6

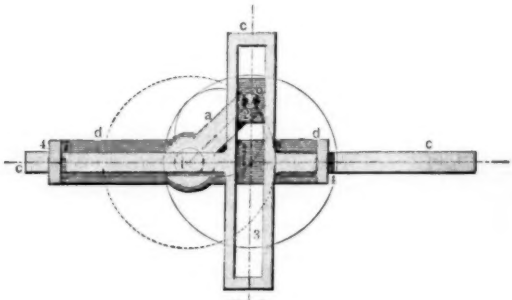


Fig. 7

* These centroids are shown on a larger scale, apart from the elements to which they belong, in Fig. 2.

of the link c being always at their points of contact. This mechanism (a being fixed) is used in Oldham's coupling, in elliptic chucks, &c. Knowing these centroids we know all about the motions of the two corresponding links in the mechanism, not only about the motions of some particular points in these links.

The centroids of kinematic chains can in general be very easily determined. Once found they make us independent to a great extent of trigonometric or algebraic formulæ, and enable us to determine all we wish to know by purely geometric graphic constructions. For technical purposes, at least, this is frequently an immense advantage. There are very few cases in which it is not more convenient for the engineer to employ a construction than a formula, if both give him the same result.

Before looking at the centroids of other mechanisms, it is necessary to examine one particular case which often occurs. Suppose that the lines PP_1 and QQ_1 in Fig. 4, or the tangents to the curves at P and Q in Fig. 5, had been parallel. It is obvious that the normal bisectors in the one case and the normals to the curve in the other then become also parallel, or, as it is for some reasons more convenient to express it, would meet at an infinite distance. The temporary center in the one case and the instantaneous center in the other are at infinity. A centroid may, therefore, contain one or more points at an infinite distance, may have, that is, one or more infinite branches. This constantly occurs in mechanism, and in some cases *every* point in the centroid is at an infinite distance. This is, however, a special case; its treatment does not offer any practical difficulty, but I cannot do more than mention its existence here.

The centroids of the connecting rod and frame of the ordinary steam engine driving mechanism (the links b and d of Fig. 8) may serve as an illustration of this. When the crank a is at right angles to d, the normals to the paths of the two points 2 and 3 are parallel. The instantaneous center of b relatively to d is, therefore, at an infinite distance. Each centroid has, therefore, a pair of infinite branches.

We may look, in conclusion, at one other case which possesses some special interest on account of the form taken by the centroids. It is shown in Fig. 9. The chain contains four links and four parallel cylinder pairs. The alternate links are equal, and the two longer links are crossed so that the chain forms an "anti-parallelogram" in every position, the angle at 2 being always equal to that at 4, and the angle at 1 to that at 3. If the link d be fixed, the links a and c become two cranks which revolve in opposite directions with a varying velocity ratio. The centroids of b and d are a pair of hyperbolæ having their foci at 2 3 and 1 4 respectively. The one rolls upon the other as b moves, the instantaneous center in the position shown being at the point of contact O, which is the point of intersection of 1 2 and 3 4. The centroids of the two shorter links are the two ellipses which are shown in dotted lines. They are confocal with the hyperbolæ, and their point of contact is always at the intersection of 1 4 and 2 3. Their form shows at once that the rotation of the axes 1 and 4 is precisely the same as that which would be communicated by a pair of elliptic spur wheels having the centroids for their pitch ellipses.

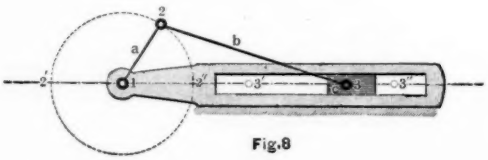


Fig. 8

In this mechanism, as in some of the others illustrated, the centroids of two *adjacent* links, as a and d, or b and c, are simply a pair of coincident points which

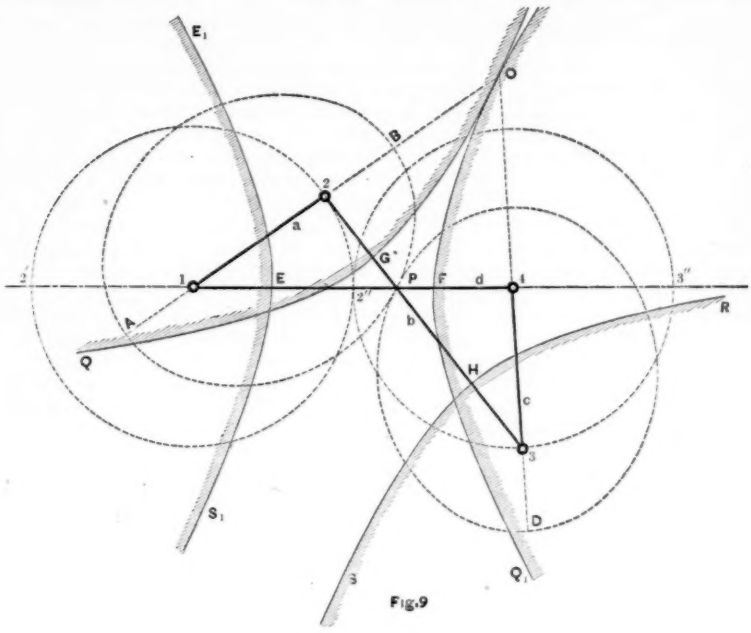


Fig. 9

roll upon each other. They form thus a limiting case of centroids, but every theorem which applies to the more extended centroidal curves applies also to these points, as can easily be seen on examination.

NOTES ON RAILROADING.

By H. P. BELL, Can. Pac. R'y.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

UNDER the head of railroading a valuable paper appeared in the April issue of this magazine. Speaking of the engineer's equipment for an exploratory survey the author says: "It need only consist of an ax, a pair of field glasses, a hand level, or two barometers, and a pair of steel climbers."

If the distance over which the exploratory survey is to extend be greater than the author of this paper seems here to contemplate, it will be found, in most cases, better to equip as follows: One hand level, one ship's sextant, one chronometer, one good pocket compass, one epitome of navigation and one book of mathematical tables — barometers optional.

In keeping a traverse or track survey with lateral sketching, it will be found useful for after reference to fix a number of points by observation. Not all engineers understand well how to use a sextant, and a few hints may be useful. Never assume the index error as constant, but try it before each observation. Always correct, if necessary, with the key the adjustment of the horizon glass, and every night that a star can be seen, see that the optical axis of the long telescope is parallel with the plane of the instrument. Do not observe without

using the long telescope, as a good contact cannot be otherwise made. Get a canvas cover made for the sextant box. Take one tin plate from the cooking outfit, and use this with a little water and a piece of Indian ink to make an artificial horizon, carry the plate under the canvas cover on top of the lid of box. The explorer can stop either in the morning, or more conveniently in the afternoon, and having worked his latitude, by dead reckoning, from the last mid-day observation, he can take the time at the place by obvervation, and work up his longitude just as at sea. Tree-top sketching, by the aid of the hand level and compass will soon make an explorer very independent of barometers, whose results, with the greatest care, are sometimes very uncertain. If the distance of survey be short, and any sort of map in existence, a smart explorer, by the aid of a sextant, without a chronometer, can make a chart of his work so true that he can always feel his way over the same ground again in any direction, and strike or avoid well-defined points, as desired, with preliminary line. I will omit reference to all those portions of Mr. Waddell's paper as unexceptionable, until he begins to describe the work of the levelers on preliminary line, in which he states that they should never approach the transit closely enough to disturb the back picket; and I would remark in this connection, that in overcoming great differences of level it is sometimes necessary to run grade upon a side hill for many miles continuously.

In such a case it will be better to put the leveler tight up to the back chainman, the chainman close to the axman, and the transit behind. The chief of the party can turn the angles with pickets as the leveler calls out to him how he is going by grade, and the transit man can make a traverse through the chopping. As the leveler marks his relation to grade frequently on the stakes, the back leveler or topographer can take note of that, and cross-section its amount out to grade, so that it may be possible afterwards to trace on the plan a complete contour line in the plane of the grade. In running grade on a side hill, the tendency will be to exaggerate the true length by preliminary line about ten per cent., so that if it be desired to locate a grade of one foot on the hundred, it will be best to run a grade of $\frac{9}{10}$ of a foot per 100 feet on the preliminary line. Coming to that part of the author's paper in which he states his preference for a Pastorelli level, I would say (as the result of practice with many different kinds of levels) that the instrument made by Spencer & Sons, Grafton street, Dublin, mounted upon an American tripod, head and legs, with only three screws in the parallel plate, will please almost any man. I would prefer the Y, as improved, to the dumpy, for the reason that the Y adjustments more combine theory with all the excellence of adjustment practically possible, than the other form of level. I say three screws in the parallel plates, because a plane will coincide with each one of any three points, in any position, but not with each one of four.

Further on, the writer makes the remark that leveling can be done very rapidly in writer, as traveling on snow shoes is so much easier than ordinary walking.

This requires explanation. It will be easier in certain places and at certain times. In other places and for long periods it will be easier to walk five miles in boots in summer than to break your own track for one mile on snowshoes. Further on, the author says of the transit man that if there be not a topographer, the transit man must keep full topographical notes, either side of the line by offset. Experience has proved that in a bush country the transit man who does this will consume more of staff and axman's time than would pay for two topographers, and, therefore, for economical reasons, in a close country topographers are a *sine qua non*.

Passing on to that portion of the author's paper in which he speaks of recording an angle to the wrong side, it may be remarked that this is quite possible, if the transit book be kept on the right and left angle principle, probably the most dangerous known. But if all angles be read from the meridian, which is done practically by keeping the back reading on the plate when the instrument is moved forward, the chances of error will be infinitesimally small. Otherwise, take one of Gurley's transits divided in four quadrants and full circle besides. Grind off the variation so as to make the needle read zero when the plates are set at zero

on the true meridian. Read the line bearings on the quadrant, and full circle besides, then look at the needle after. The chances of error will be reduced to the lowest point, and the probability of discovering an error, should one be made, will be raised almost to certainty. Many men dislike this system as involving too much work, but it saves time in the long run, and those who have used it never regret.

Further on the author of the paper referred to, says: "Locations are sometimes made by taking the angles and distances directly from the plot and laying them out on the ground, but the ordinary way is to use the plot simply as a guide, to run in the tangents and put the curves in to suit."

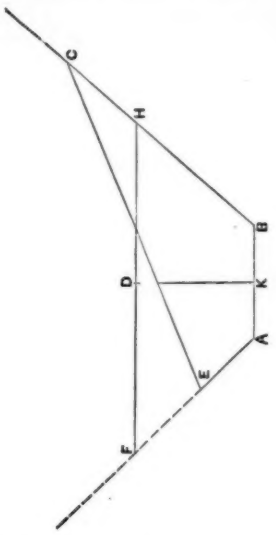
There are many cases on record where men have had to do a certain amount of work in a certain amount of time, the time being regulated by the provisions on hand and the means of transport. Under these circumstances it is often best to run the center line in at once, without going to apex. There are other reasons. If the timber be extra heavy, much time will be lost in chopping that may be saved by doing all this after the line is cleared and the first marks burnt and obliterated.

By taking frequent offsets to the trial line, and having a tracing of the work as laid down in his pocket, the engineer can, by careful attention to simple American rules, keep his line in position (provided he does not make angular errors) without running to apex.

If he suspects an error let him take an observation at once.

Passing on to that part of the author's paper where he treats of the method of calculating quantities from cross sections for construction, it is noticeable that he omits the calculation of quantities for a contract estimate altogether.

As there is often little time to spare over this kind of work, I will try to describe a method of estimating excavation of cuttings and cubes of embankments, introduced by me on the Intercolonial Railway in 1869, and on the Canada Pacific Railway in 1874. It is merely a modification of the method set forth by Mr. I. C. Trautwine in his earthwork tables, depending on the projection of a supposed level surface line, whose vertical ordinates, from grade to new or supposed surface, would produce the same quantities found by calculation from dimensions on sidelong ground. Having plotted the necessary preliminary cross sections from field notes, these are to be equalized by parallel rules to equivalent area under level surface as follows:



Let ABCE be a cross section of a cutting; produce the slope EA indefinitely; assume any point F by guess, a little over the center; lay the parallel ruler from C to F, move to E and mark H—join FH.

If now the line FH be horizontal, or even nearly so, DK will be the proper height to transfer to the profile at the point where prism is situated. Having so equalized all the cross sections and produced a new surface line with supposed level cross section, the quantities may be taken from tables.

If FH be not nearly horizontal, assume a new point F and repeat the process. If the surface line itself be crooked, proceed, first, by rules for equalizing a crooked fence, and afterwards as above directed.

Using this equalized surface line with a set of diagrams made for the particular bases in use, to show the number of feet in length for each successive yard in depth that it takes to make 100 cubic

yards, the quantities may then be taken from the profile by measurement and inspection with a speed and accuracy incredible to those who have not seen it done.

The writer of the last month's paper refers to ditching. I may say of this class of work that the assistant engineer, who can keep an orderly record of borrow ditching, that is cut and re-cut at all manner of irregular distances, shapes and odd times, has kept probably the most difficult class of work in order known to engineers, especially if it be in soft ground, liable to changes of form from drainage, pressure, and other causes. It is a mistake to suppose that the heaviest kind of work is the most difficult to manage or to measure. On the contrary, there is no work more easy to keep track of than plain line cuttings and borrow pits in solid ground.

MOLECULAR ELECTRO-MAGNETIC INDUCTION.

By PROF. D. E. HUGHES, F. R. S.

From "English Mechanic and World of Science."

THE induction currents balance shows how extremely sensitive it is to the slightest molecular change in the composition of any metal or alloy, and it gives strong evidence of a peculiarity in iron and steel which its magnetic properties alone failed to account for. We could with all non-magnetic metals easily obtain a perfect balance of force by an equivalent piece of the same metal, but in the case of iron, steel and nickel it was with extreme difficulty that I could obtain a near approach to a perfect zero. Two pieces of iron cut off the same bar or wire, possessing the same magnetic moment, never gave identical results; the difficulty consisted, that notwithstanding each bar or wire could be easily made to produce the same inductive reaction, the time during which this reaction took place varied in each bar; and although I could easily change its balancing power as regards inductive force by a change in the mass of the metal, by heat or magnetism, the zero obtained was never equal to that obtained from copper or silver. This led me to suppose the existence of a peculiarity in magnetic metals which could not be accounted for except upon the hypothesis that there was a cause, then unknown, to produce the invariable effect.

In order to fully understand the mode of experiments, as well as the results obtained, I will first describe the apparatus employed.

The electro-magnetic induction balance consists—1st, of an instrument for producing the new induction current; 2nd, sonometer or balancing coils; 3rd, rheotome and battery; 4th, telephone.

The essential portion of this new balance is that wherein a coil is so arranged that a wire of iron or copper can pass freely through and forming its axis. The iron or copper wire rests upon two supports 20 centims. apart; at one of these the wire is firmly clamped by two binding screws; the opposite end of the wire turns freely on its support, the wire being 22 centims. long, having 2 centims. projection beyond the support, in order to fasten upon it a key or arm, which shall serve as a pointer upon a circle giving the degrees of torsion which the wire receives from turning this pointer. A binding screw allows us to fasten the pointer at any degree, and thus preserve the required stress the time required. The exterior diameter of the coil is $5\frac{1}{2}$ centims., having an interior vacant circular space of $3\frac{1}{2}$ centims., its width is 2 centims.; upon this is wound 200 meters of No. 32 silk-covered copper wire. This coil is fastened to a small board, so arranged that it can be turned through any desired angle in relation to the iron wire which passes through its center, and it can also be moved to any portion of the 20 centims. of wire, in order that different portions of the same wire may be tested for a similar stress. The whole of this instrument, as far as possible, should be constructed of wood, in order to avoid, as far as possible, all disturbing inductive influences of the coil.

The iron wire at its fixed end is joined or makes contact with a copper wire, which returns to the front part of the dial under its board and parallel to its coil, thus forming a loop; the free end of the iron wire is joined to one pole of the battery, the copper wire under the board is joined to the rheotome and thence to the battery.

The coil is joined to the telephone; but, as in every instance we can either pass the battery through the wire, listening to its inductive effects upon the wire, or the reverse of this, I prefer, generally, in order to have no voltaic current passing through the wire, to join the iron wire and its loop direct to the telephone, passing the voltaic current through the coil.

In order to balance, measure, and know the direction of the new induction currents by means of a switching key, the sonometer I described to the Royal Society is brought into the circuit. The two exterior coils of the sonometer are then in the circuit of the battery, and of the coil upon the board containing the iron wire or stress bridge. The interior or movable coil of the sonometer is then in the circuit of the iron wire and telephone. Instead of the sonometer constructed as described at the place cited, another form is preferred. This consists of two coils only, one of which is smaller and turns freely in the center of the outside coil. The exterior coil being stationary, the center coil turns upon an axle by means of a long (20 centims.) arm or pointer, the point of which moves over a graduated arc or circle. Whenever the axis of the interior coil is perpendicular to the exterior coil no induction takes place, and we have a perfect zero; by turning the interior coil through any degree we have a current proportional to this angle, and in the direction in which it is turned. As this instrument obeys all the well-known laws for galvanometers, the readings and evaluations are easy and rapid.

If the coil upon the stress bridge is perpendicular to the iron wire, and if the sonometer coil is at zero, no currents or sounds in the telephone will be perceived, but the slightest current in the iron wire produced by torsion will at once be heard; and by moving the sonometer coil in a direction corresponding to the current a new zero will be obtained, which will not only balance the force of the new current, but indicate its value. A perfect zero, however, will not result with the powerful currents obtained by the torsion of 2 milims. diameter iron wire; we then require special arrangements of the sonometer which are too complicated to describe here.

The rheotome is a clockwork, having a rapid revolving wheel which gives interruptions of currents in fixed cadences, in order to have equal intervals of sounds and silence. I employ four bichromate cells or eight Daniell's elements, and they are joined through this rheotome to the coil on the stress bridge, as I have already described.

The magnetic properties of iron, steel, nickel, and cobalt have been so searchingly investigated by ancient as well as by modern scientific authors, that there seems little left to be known as regards their molar magnetism. I use the word molar here simply to distinguish or separate the idea of a magnetic bar of iron or steel magnetized longitudinally or transversely from the polarized molecules which are supposed to produce its external magnetic effects.

Molar magnetism, whilst having the power of inducing an electric current in an adjacent wire, provided that either has motion or a change in its magnetic force, as shown by Faraday in 1832, has no power of inducing an electric current upon itself or its own molar constituent, either by motion or change of its magnetic moment. Molecular magnetism (the results of which, I believe, I have been the first to obtain) has no, or very feeble, power of inducing either magnetism or an electric current in an adjacent wire, but it possesses the remarkable power of strongly reacting upon its own molar wire, inducing (comparatively with its length) powerful electric currents, in a circuit of which this forms a part.

In some cases, as will be shown, we may have both cases existing in the same wire; this occurs when the wire is under the influence of stress, either external or internal; it would have been most difficult to separate these two, as it was in my experiments with the induction balance, without the aid of my new method.

Ampere's theory supposes a molecular

magnetism or polarity, and that molar magnetism would be produced when the molar magnetism became symmetrical; and his theory, I believe, is fully capable of explaining the effects I have obtained, if we admit that we can rotate the paths of the polarized molecules by an elastic torsion. Matteucci made use of an inducing and secondary coil in the year 1847, by means of which he observed that mechanical strains increased or depressed the magnetism of a bar inside this coil. Wertheim published in the *Comptes rendus*, 1852, some results similar to Matteucci; but in the *Annales de Chimie et de Physique*, 1857, he published a long series of most remarkable experiments, in which he clearly proves the influence of torsion upon the increment or decrement of a magnetical wire. Villari showed increase or diminution of magnetism by longitudinal pull according as the magnetizing force is less or greater than a certain critical value. Wiedermann, in his remarkable work, "Galvanismus," says that an iron wire, through which an electric current is flowing, becomes magnetized by twisting the wire. This effect I have repeated, but found the effects very weak, no doubt due to the weak battery I use, viz., four quart bichromate cells. Sir W. Thomson shows clearly in his remarkable contribution to the *Phil. Trans. Roy. Soc.*, entitled "Effects of Stress on the Magnetization of Iron, Nickel and Cobalt," the critical value of the magnetization of these metals under varying stress, and also explains the longitudinal magnetism produced by Weidermann as due to the outside molar twist of the wire, making the current pass as in a spiral round a fixed center. Sir William Thomson also shows clearly the effects of longitudinal as well as transversal strains, both as regards its molar magnetism and its electric conductivity. My own researches convince me that we have in molecular magnetism a distinct and separate form of magnetism from that when we develop, or render evident, longitudinal or transversal magnetism, which I have before defined as molar.

Molecular magnetism is developed by any slight strain or twist other than longitudinal, and it is only developed by an elastic twist; for, however much we may twist a wire, provided that its fibers are not separated, we shall only have the result due to the reaction of its remaining elasticity. If we place an iron wire, say 20 centims. long, 1 millim. diameter, in the axis of the coil of the electro-magnetic balance, and if this wire is joined, as described, to the telephone, we find that on passing an electric current through the inducing coil no current is perceptible upon the iron wire; but if we give a very slight twist to this wire at its free end—one-eighteenth of a turn, or 20°—we at once hear, clear and comparatively loud, the currents passing the coil: and although we only gave a slight elastic twist of 20° of a whole turn, and this spread over 20 centims. in length, making an extremely slight molar spiral, yet the effects are more powerful than if, using a wire free from stress, we turned the whole coil 40°. The current obtained when we turn the coil, as just mentioned, is secondary, and with the coil at any angle any current produced by its action, either on a copper, silver, iron or steel wire; in fact, it is simply Faraday's discovery, but the current from an elastic twist is no longer secondary under the same conditions, but tertiary, as I shall demonstrate later on. The current passing through the coil cannot induce a current upon a wire perpendicular to itself, but the molecules of the outside of the wire, being under a greater elastic stress than the wire itself, they are no longer perpendicular to the center of the wire, and consequently they react upon this wire as separate magnets would upon an adjacent wire. It might here be readily supposed that a wire having several twists, or a fixed molar twist of a given amount, would produce similar effects. It, however, does not, for in most cases the current obtained from the molar twists are in a contrary direction to that of the elastic torsion. Thus, if I place an iron wire under a right-handed elastic twist of 20°, I find a positive current of 50° sonometer; but if I continue this twist so that the index makes one or several entire revolutions, thus giving a permanent molar twist of several turns, I find upon leaving the index free from any elastic torsion, that I have a permanent current of 10°, but it is no longer positive, but negative, requiring that we should give an elastic torsion in the pre-

vious direction, in order to produce a positive current. Here a permanent elastic torsion of the molecules is set up in the contrary direction to its molar twist, and we have a negative current, overpowering any positive current which should have been due to the twisted wire.

The following table shows the influence of a permanent twist, and that the current obtained when the wire was freed from its elastic torsion was in opposition to that which should have been produced by the permanent twist. Thus, a well-softened iron wire, 1 millim. in diameter, giving 60° positive current for a right-handed elastic torsion of 20°, gave after 1.80° permanent torsion a negative current of 10°.

1 complete permanent torsion (right-handed negative)				10
2	"	"	"	15
3	"	"	"	15
4	"	"	"	16
5	"	"	"	12
6	"	"	"	10
7	"	"	"	5
8	"	"	"	4
9	"	"	"	3
10	"	"	"	3

At this point the fibers of a soft wire commence to separate, and we have no longer a complete wire, but a helix of separate wires upon a central structure.

If now, instead of passing the current through the coil, I pass it through the wire, and place the telephone upon the coil circuit, I find that I obtain equally as strong tertiary currents upon the coil as in the previous case, although in the first case there was produced longitudinal electro-magnetism in the perpendicular wire by the action of the coil; but in the latter case none of the most feeble electro-magnetism was produced, yet in these two distinct cases we have a powerful current produced not only upon its own wire, but upon the coil, thus proving that the effects are equally produced both on the wire and coil.

If we desire, however, in these reversible effects to produce in both cases the same electromotive force, we must remember that the tertiary current, when reacting upon its own short wire, produces a current of great quantity, the coil one of comparative higher intensity. We can, however, easily convert the great quantity of the wire into one of higher tension, by passing it through the primary of a small induction coil whose resistance is not greater than one ohm. We can then join our telephone, which may be one of a high resistance, to the secondary of this induction coil, and by this means, and without changing the resistance of the telephone, receive the same amount of force, either from the iron wire or the coil.

Finding that iron, steel, and all magnetic metals produce a current by a slight twist, if now we replace this wire by one of copper or non-magnetic metals we have no current whatever by an elastic twist, and no effects, except when the wire itself is twisted spirally in helix, and whatever current we may obtain from copper, &c., no matter if from its being in spiral or from not being perpendicular to the axis of the coils, the currents obtained will be invariably secondary and not tertiary. If we replace the copper by an iron wire, and give it a certain fixed torsion, not passing its limit of elasticity, we find that no increase or decrease takes place by long action or time of being under strain. Thus, a wire which gave a sonometric force of 50° at the first observation, remained perfectly constant for several days until it was again brought to zero by taking off the strain it had received. Thus, we may consider that as long as the wire preserves its elasticity, exactly in the same ratio will it preserve the molecular character of its magnetism.

It is not necessary to use a wire to produce these effects; still more powerful currents are generated in bars, ribbons, or sheets of iron; thus, no matter what external form it may posses, it still produces all the effects I have described.

It requires a great many permanent twists in a wire to be able to see any effect from these twists; but if we give to a wire, 1 millim. diameter, 40 whole turns (or until its fibers become separated) we find some new effects; we find a small current of 10° in the same direction as its molar twist, and on giving a slight twist (20°) the sonometric value of the sound obtained is 80°, instead of 50°, the real value of a similar untwisted wire; but its explanation will be found by twisting the wire in a contrary direction to its molar twist. We can now approach the zero but never produce a current in the contrary direction, owing

to the fact that by the spiral direction, due to the fibrous molar turns, the neutral position of its molecules are no longer parallel with its wire, but parallel with its molar twist, consequently an elastic strain in the latter case can only bring the molecules parallel with its wire, producing no current, and in the first case the angle at which the reaction takes place is greater than before, consequently the increased value of its current.

The measurements of electric force mentioned in this paper are all sonometric on an arbitrary scale. Their absolute value has not yet been obtained, as we do not, at our present stage, require any except comparative measures. Thus, if each wire is of 1 millim. diameter and 20 centims. long, all render the same stress in the axis of ts coil. I find that the following are he sonometric degrees of value:

Soft iron..... ...	60°	Tertiary current.
Hard drum iron....	50°	" "
Soft steel.....	45°	" "
Hard tempered steel	10°	" "
Copper, silver, &c..—0°		
Copper helix, I centim. diameter, 20 turns in 20 centims	45°	Secondary currents.
Iron, spiral, ditto...	45°	" "
Steel.....	45°	" "

The tertiary current increases with the diameter of the wire, the ratio of which has not yet been determined; thus, an ordinary hard iron wire of one millim. diameter giving 50°, one of two millims. diameter gave 100°; and the maximum of force obtained by any degree of torsion is at or near its limit of elasticity, as if in same time we also pass this point, producing a permanent twist, the current decreases, as I have already shown in the case of a permanent twist. Thus, the critical point of one millim. hard iron wire was 20° of torsion, but in hard steel it was 45°.

Longitudinal strains do not produce any current whatever, but a very slight twist to a wire, under a longitudinal strain, produces its maximum effects; thus, 20° of torsion being the critical point of iron wire, the same wire, under longitudinal strain, required but from 10° to 15°. It is very difficult, however, to produce a perfect longitudinal strain alone. I have, therefore, only been able to try the effect of longitudinal strain on fine wires, not larger than one millim. in diameter, but as in all cases no effect whatever was produced by longitudinal strain alone, I believe none will be found if absolutely free from torsion. The molecules in a longitudinal strain are equally under an elastic strain as in torsion, but the path of their motion is now parallel with its wire, or the zero of electric inductive effect, but the compound strain, composed of longitudinal and transverse, react upon each other, producing the increased effect due to the compound strain.

The sonometer is not only useful for showing the direction of the current and measuring it by the zero method, but it also shows at once if the current measured is secondary or tertiary. If the current is secondary its period of action coincides with that of the sonometer, and a perfect balance, or zero of sound, is at once obtained, and its value in sonometric degrees given; but if the current is tertiary, no zero is possible, and if the value of the tertiary is 60°, we find 60° the nearest approach to zero possible. But by the aid of separate induction coils to convert the secondary into a tertiary, a perfect zero can be obtained if the time of action and its force correspond to that which we wish to measure.

If I place a copper wire in the balance, and turn the coils at an angle of 45°, I obtain a current which the sonometer gives a perfect zero at 50°, proving, as already said, that it is secondary. If I now replace the copper by an iron wire, the coil remaining at 45°, I have again exactly the same value for the iron as copper, viz., 50°, and in both cases secondary. Now, it is evident that in the case of the iron wire there was produced at each passage of the current a strong electro-magnet; but this longitudinal magnetism did not either change the character of the current or its value in force.

A most beautiful demonstration of the fact that longitudinal magnetism produces no current, but that molecular magnetism can act equally as well, no matter the direction of the longitudinal magnetism, consists in forming an iron wire in a loop, or taking two parallel but separate wires, joined electrically at their fixed ends, the free ends being each connected with the circuit, so that the cur-

rent generated must pass up one wire and down the adjacent one. On testing this loop, and if there are no internal strains, complete silence or absence of current will be found. Now, giving a slight torsion to one of these wires in a given direction, we find, say, 50° positive; twisting the parallel wire in a similar direction produces a perfect zero, thus the current of the second must have balanced the positive of the first. If, instead of, twisting it in similar directions, we twist it in the contrary direction, the sounds are increased in value from 50° positive to 100° positive, showing, in this latter case, not only a twofold increase of force, but that the currents in the iron wires traveled up one wire and down the other, notwithstanding that both were strongly magnetic by the influence of the coil in one direction, and this experiment also proves that its molar magnetism had no effect, as the currents are equally strong in both directions, and both wires can double or efface the currents produced in each. If, instead of two wires, we take four, we can produce a zero, or a current of 200°, and with twenty wires we have a force of 1,000°, or an electromotive force of two volts. We have here a means of multiplying the effects by giving an elastic torsion to each separate wire, and joining them electrically in tension. If loops are formed of one iron and one copper wire, we can obtain both currents from the iron wire, positive and negative, but none from the copper; its *rôle* is simply that of a conductor upon which torsion has no effect.

I have already mentioned that internal strains will give out tertiary currents, without any external elastic strain being put on. In the case of iron wire, these disappear by a few twists in both directions, but in flat bars or forged iron, they are more permanent; evidently, portions of these bars have an elastic strain, whilst other portions are free, for I find a difference at every inch tested; the instrument, however, is so admirably sensitive, and able to point out not only the strain, but its direction, that I have no doubt its application to large forged pieces, such as shafts or cannon, would bring out most interesting results, besides its practical utility; great care is therefore necessary in these experiments that we have a wire free from internal strains, or that we know their value.

Magnetizing the iron wire by a large steel permanent magnet has no effect whatever. A hard steel wire thus placed becomes strongly magnetic, but no current is generated, nor has it any influence upon the results obtained from molecular movement, as in elastic torsion. A flat wide iron or steel bar shows this better than iron wire, as we can here produce transversal, instead of longitudinal, but neither shows any trace of the currents produced by molecular magnetism. I have made many experiments with wires and bars thus magnetized; but as the effect in every case was negative when freed from experimental errors, I will not mention them; but there is one very interesting proof which the instrument gives, that longitudinal magnetism first passes through its molecular condition before and during the discharge, or recomposition of its magnetism. For this purpose, using no battery, I join the rheotome and telephone to the coil, the wire having no exterior circuit. If I strongly magnetize the two ends of the wire, I find by rapidly moving the coil, that there is a Faradaic induction of 50° at both poles, but very little or none at the center of the wire; now fixing the coil at the central or neutral point of the wire, and listening intently, no sounds are heard; but the instant I give a slight elastic torsion to the free pole, a rush of electric tertiary induction is heard, whose value is 40°. Again, testing this wire by moving the coil, I find only a remaining magnetism of 10, and upon repeating the experiment of elastic torsion, I find a tertiary of 5; thus can we go on gradually discharging the wire, but its discharge will be found to be a recomposition, and that it first passed through the stage I have mentioned.

Heat has a very great effect upon molecular magnetic effects. On iron it increases the current, but in steel the current is diminished. For experimenting on iron wire, which gave a tertiary current of 50° positive (with a torsion of 20°), upon the application of the flame of a spirit lamp, the force rapidly increases (care being taken not to approach red heat) until the force is doubled, or 100 positive. The same effects were obtained

in either direction, and were not due to a molar twist or thermo-current, as if care had been taken to put on not more than 10° of torsion, the wire came back to zero at once on removal of the torsion. Hard-tempered steel, whose value was 10° whilst cold, with a torsion of 45°, became only 1° when heated, but returned (if not too much heated) to 8° when cold. I very much doubted this experiment at first, but on repeating the experiment with steel several times, I found that on heating it, I had softened the extreme hard (yellow) temper to that of the well-known blue temper. Now, at blue temper, hot, the value of steel was but 1° to 2°, whilst soft iron of a similar size gave 50° of force cold, and 100° at red heat. Now, as I have already shown that the effects I have described depend on molecular elasticity, it proves at least, as far as iron and steel are concerned, that a comparatively perfect elastic body, such as tempered steel, has but a slight molecular elasticity, and that heat reduces it, but that soft iron, having but little molar elasticity, has a molecular elasticity of a very high degree, which is increased by heat.

The objects of the present paper being to bring the experimental facts before the notice of the Royal Society, and not to give a theoretical solution of the phenomena, I will simply add, that if we assume with Poisson, that the paths of the molecules of iron are circles, and that they become ellipses by compression or strain, and also that they are capable of being polarized, it would sufficiently explain the new effects.

Joule has shown that an iron bar is longer and narrower during magnetization than before, and in the case of the transverse strain, the exterior portions of the wire are under a far greater strain than those near the center, and as the polarized ellipses are at an angle with the molecules of the central portions of the wire, its polarization reacts upon them, producing the comparatively strong electric currents I have described.

STEEL.*

By J. RILEY, General Manager to the Steel Company of Scotland.

From "Iron."

I DO not think any justification is necessary for bringing this subject before you; but were such the case, I think it would be found in the increasing magnitude of the number and extent of the works engaged in the manufacture of steel in this district, and in the large and increasing measure of the use of that material in our midst, more especially in connection with shipbuilding and engineering. With that spirit of enterprise and enlightened progress which is the characteristic of those engaged in these pursuits on the Clyde, the metal "mild steel"—which has been called the metal of the future—had not been long under the notice of the public ere they commenced its use, and the results of their extended experience of its many good qualities has been so satisfactory that, being able to recommend it to their clients, the demand for this class of steel has increased constantly and rapidly—indeed, at a rate which has heavily taxed the powers of those engaged in its manufacture. I shall have occasion later to return to this, and at present would only say that, only about three years ago, the Steel Company of Scotland—and at that time the only firm in Scotland engaged largely in the manufacture of steel—found that less than 100 tons of "mild steel" produced weekly enabled them to meet all demands upon them; whereas at present they have had difficulty in executing all calls upon them when producing not less than 1400 tons weekly, and their efforts have been supplemented by those of one or two other firms in Scotland, who have been induced to commence this manufacture by the largeness of the present and prospective demand. It does indeed seem probable that in a very short time Lanarkshire

*Delivered at the Naval and Marine Engineering Exhibition, Glasgow.

will be the foremost of the "mild steel" making districts in Great Britain—if not of the world; for I take it that the works now complete and in progress will shortly have a producing power of not far short of 4000 tons weekly of "mild steel" alone. In their total-producing capacity they will probably have a yield of near 6000 tons of ingots, requiring about 4500 to 5000 tons of hematite pig iron weekly in its production. Up till recently the pig iron used in this manufacture was brought from England; now, however, many of the makers of pig iron in this district have turned their attention to making hematite iron; and I expect that the whole of our requirements will shortly be met at home, and thus the superabundant make of ordinary Scotch pig iron will be largely reduced.

I doubt not that many of the outside public have been surprised and perplexed at the idea of steel being used in the construction of ships and boilers, the name "steel" being associated in their minds with sharp cutting instruments of hard and possibly brittle character. In the same way, but of course not to the same extent, many who have been engaged in the use of iron for a long period and thoroughly understand its characteristics, but who have had no practical acquaintance with the newer classes of "steel," have no doubt had many misgivings as to the propriety of its use in these directions, and also of their own ability to deal successfully with it, should they be required to use it in their ordinary occupations. These ideas have contributed largely to that disinclination to adopt the "new material" with which steelmakers have been so long and so successfully contending. The application of the term "steel" to the newer classes of this metal was indeed unfortunate, so far as makers were concerned, and has contributed not a little to the many difficulties they have experienced in the conduct of their business. Even in the minds of experts there has been something approaching to a confusion of ideas regarding these metals through the use of this term "steel," and some efforts have been made to get over the difficulty by a division into classes, whereby the milder or softer should be called "ingot iron," or homogeneous metal, while the harder retained the older designation of steel, but difficulties which I need not here enumerate have prevented the general adoption of this proposal. Now the definition is pretty generally accepted, that steel is an alloy of iron which is cast while in a fluid state into a malleable ingot. Yet this does not cover some of the steels to which I shall have to refer.

The history of steel is of great and increasing interest whether we consider the various processes by which it has been and is produced, the inventors of these different processes, with the vicissitudes of fortune through which both have passed, or its application to the various requirements of a constantly advancing civilization. I do not, however, propose to refer in more than an incidental manner to some of these matters, but I trust that the facts I may lay before you may be found of sufficient interest to warrant their introduction. Steel, as I have said, is an alloy of iron, and this principally with carbon, and the aim of the manufacturer is to obtain the alloy with such proportions of each as shall best fit it for the purpose for which it is intended. In order to accomplish this he may adopt some one of the following methods: Having ore of sufficient purity he may reduce it and obtain malleable iron or steel, by one or other of the direct processes as they are called; thus dispensing with the usual intermediate stages, by which the ore is first reduced in the blast furnaces and pig iron produced, to be afterwards, by puddling, &c., made into bar or wrought iron; or, taking the wrought iron so produced, and which may contain too little carbon for his purpose, he may seek by various means to increase its proportion to the iron; or, on the other hand, having crude or pig iron, which contains a varying amount of carbon, but in all cases too much to admit of its being wrought—that is, hammered, rolled or welded—he may seek to reduce the proportion of carbon present either by removing some of it by oxidation, or by diluting it by increasing the proportion of the iron. All the various processes for producing steel, whether of ancient or modern times, are based on one or other of these principles, or a combination of them. It is my purpose to-night

to describe these various processes, and I trust I may be able to do so in an intelligible manner. The most primitive method of making steel of which we have any knowledge, is that practiced by the natives of India, and some other countries where the ore is reduced in bloomeries, as they are sometimes termed, and of which the Catalan process may be taken as an illustration. Only the richest and purest ores are used. These are heated in contact with carbon—*i. e.*, charcoal—until reduction takes place, when it is only necessary to remove the spongy mass, and, by hammering, to bring about the aggregation of the particles. The iron thus obtained is broken into small pieces and selected. In making the celebrated Wootz steel, the natives of India pack small pieces of this malleable iron with wood in crucibles, which are then heaped over with some green leaves and clay. About two dozen of these crucibles are packed in one furnace; they are covered over with fuel, and blast is applied for about two and a half hours, when the operation is terminated. The crucibles are broken when cold, and the small cakes of steel removed.

The fact that the production of wrought iron or steel, direct from the ore, has excited so much interest in the minds of metallurgists is not to be wondered at when the cost of reduction by means of the blast furnace, and the subsequent necessary operations are borne in mind. Hence there have been many proposals for accomplishing this desirable end, but as few of them have passed the experimental stage, and as none have yet been commercially successful on a large scale, I do not think it necessary to take up your time with a description of any of them. I would simply indicate that the processes of Chenot, of Blair, and of Siemens, appear to have come nearest achieving the object aimed at. In dealing with wrought iron by what is known as the "cementation process," bars are rolled or hammered to the required section. They are then cut to the proper length, and charged into furnaces known as converting furnaces. The pots or troughs on the beds of these furnaces, which are made of refractory materials, are strewed with charcoal powder to the thickness of one or two inches. A layer of bars is placed on this bed, and covered with charcoal, on which are again laid alternate layers of bars and charcoal until the troughs are nearly filled, when they are covered several inches thick with charcoal, and afterwards with what is called "wheelswarf," produced at the grinding stones. All the apertures of the furnace are then closed, and the fires lighted on the grates. In a few days the furnace attains its full heat, at which it is kept for several days according to the degree of hardness required, depending upon the amount of carbon combined with the iron. The progress made in carburization is tested from time to time after the sixth day by drawing bars from the troughs. When these prove satisfactory, the fire is heaped up with small coal, and then allowed to die out. The furnaces are of different capacities, varying from 15 to 30 tons; and this cementation process, as it is called, may be said to occupy about three weeks. The bar steel produced is known as "blistered steel," because when discharged from the furnace the bars are found partially covered by small raised portions of the metal, resembling blisters. On breaking the bars across, the texture is seen to be no longer fibrous, but granular or crystalline; the color is white, and the crystals are large in proportion to the amount of carbon absorbed. "Shear steel" is the product from these bars of blistered steel, broken into lengths, bundled, or made into faggots, which are rolled or hammered out at welding heat to the form required.

This operation is repeated until a sufficiently uniform texture is obtained. All the loose parts and seams of the blistered steel are closed, and it is now capable of being highly polished; it is also more malleable, and can be forged into shears, edge-tools, and cutting instruments. The value of the steel increases with the amount of hammering which it receives, and the terms "double shear," "single shear," &c., express the amount of doubling and welding which the bars have undergone. Again, steel is made from wrought iron by fusion with carbonaceous matter, as in the case of the Indian Wootz process, previously described, and by a process introduced by Mushet, which consists in melting malle-

able scrap iron with charcoal and oxide of iron in crucibles.

Crucible steel is made in two classes of furnaces, with which it may be as well that you should become acquainted at this point. The first and oldest form is that known as the coke or melting-hole furnace. The furnace, or melting hole, is a small square or oblong chamber, about three feet deep, and from one and a half to two feet square, lined with refractory material, such as firebrick, or the siliceous stone known as gannister. The top of the furnace is placed level with the floor of the casting house, the grate bars and ashpit being accessible from below through a vaulted cellar or cave. The cover of the furnace is a square of firebrick, set in an iron frame, with a projecting handle. There is a short flue near the top of the furnace communicating with the stack, which is about 40 feet high, in order to command a strong draught. Several furnaces are usually arranged in longitudinal series on opposite sides of the casting house, leaving the center of the floor clear for placing the moulds. Usually two pots or crucibles are placed in a furnace. They stand upon cylindrical discs of firebricks, resting on the grate bars. Previously to being used they require to be gradually heated to redness in an open fire or annealing grate, which is done by placing them in batches of twenty, bottom upwards, together with their covers, upon a bed of red-hot coal in the grate; the intermediate space is then filled with coke, and the fire is urged until the necessary heat has been obtained. The pots are then removed to the melting furnaces, and fixed in position on the stand. The fires are replenished with coke, and as soon as they have been brought up to a strong heat, which takes place in about twenty minutes, the charge, properly assorted and broken into small pieces, is introduced through a wrought-iron funnel; after which the cover is placed on the pot, and the full heat of the furnace is given for three and a half hours; during which time fresh fuel is added every three-quarters of an hour. When the fusion is complete, which is ascertained by removing the cover, and searching the contents of the crucible with a pointed rod, the crucible is cleared from adherent slaggy masses by stirring below the grate, and is then lifted out by the furnace men with a suitable pair of tongs. The ingot mould, made of cast iron, is blackened or coated by various means, and the contents of the crucible, after being allowed to cool for a short time, are then poured into the mould, and its mouth is covered with a plug of cast iron or a shovelfull of sand, in order to prevent the top of the ingot becoming spongy by the escape of gases before solidification.

The crucible being cleaned is then returned to the furnace for a second melting. The charge is somewhat reduced, because it is found that the crucibles are reduced in strength at the line of the surface of the previous charge, where a cutting action has taken place by the slag from the fluxes employed; consequently, the consumption of coke and the time of fusion are both reduced in proportion. The furnace is allowed to cool after from three to five meltings have been made, as there is no advantage to be gained by keeping it constantly heated, owing to the corrosion of the lining bricks, produced by the very high temperature, whereby the capacity and power of consuming fuel is increased, without a corresponding increase in the amount of steel melted. I have thought it best in this connection to give you a description of the Siemens crucible furnace, which depends for its great advantages over the common furnace, or the application of the regenerative system and the use of gaseous fuel, although I have not yet brought either of these under your notice. This furnace is thus described by its inventor: "In the application of the regenerative system to the fusion of steel in closed pots or crucibles, the melting chamber, containing generally twenty-four pots, is constructed in the form of a long trench, 3 feet 6 inches wide at the bottom, and gathered in to under 2 feet at the top. The sides of the melting chamber are arched, both horizontally and vertically, to keep them from sinking together in working, and the work is strengthened by cross-walls at intervals. The pots are set in a double row along the center of the melting chamber, and the flame passes from side to side, the gas and air from the regenerators being introduced alternately from one side, and from the other, oppo-

site to each pair of pots. The melting chamber is closed above by loose fire-brick covers, which are drawn partly off in succession by means of a lever suspended from a pulley above the furnace, when the pots are to be charged or drawn out. The pots stand in a bed of finely-ground coal dust, resting on iron plates. The coke dust burns away only very slowly if it is made of hard coke and finely ground; and it presents the great advantage of remaining always in the form of a loose, dry powder, in which the pots stand firmly, while every other material that I have tried either softens in the intense heat, or sets, after a time, into a hard, uneven mass, in which the pots do not stand well. The process of melting carried out in this form of gas furnace is the same in all respects as that in the small air furnaces, or melting holes fired with coke, which are commonly employed; but a great saving is effected in the cost of fuel, and in the number of crucibles required. The ordinary consumption of hard coke is between three and four tons per ton of steel fused; while in the gas furnaces the same work may be done by the expenditure of 15 to 20 cwt. of common coal slack, the cost being, say, 5 per cent. against 75 per cent. per ton of melted steel."

The crucibles used in both the furnaces described are made of mixtures of different kinds of fire clay, with a certain proportion of ground potsherds and coke dust. The usual size is from 16 to 18 inches in height, and from 5 to 7 inches diameter at the mouth, with a slight belly at about two-thirds of the height from the bottom; the capacity varies from 35 to 80 lbs. Plumbago pots are now sometimes used, and found to be of advantage in different ways. When any large masses of cast steel are required, the contents of all the crucibles are either poured into a foundry ladle before filling the mould, or the pouring is so arranged that, by bringing up relays of fresh pots, a constant stream may be kept up without intermission. Such an operation is one of great interest, and requires careful preparation and organization so perfect, that hundreds of crucibles must be ready to be taken out of the furnaces in quick succession, and their contents poured into the common receptacles. The finest qualities of crucible cast steel are made by melting cement steel, made from the finest materials, such as the best brands of Swedish iron. The celebrated Huntzman steel is thus prepared; and it must be understood that the quality of the resulting steel depends, in the largest measure, upon the most careful assorting of the materials charged, which is done by workmen skilled in judging of the blistered steel, &c., to be used.

We come now to consider the different methods adopted for producing steel from crude or pig iron. What are known as finery furnaces have been largely used on the Continent for the production of what is known as "natural steel." They are all pretty much of the same type, but vary somewhat in form and dimensions. If you will kindly bear in mind the form of the Catalan forge, during the following description of the process, it may help you to a clearer realization of the operations. There is a tuyere blowing into the metal on an open fire, only the blast is more powerful than in the more primitive furnace. This process was formerly practiced, to a considerable extent, in Styria, Westphalia, and other parts of Europe, but has been rapidly superseded by more improved processes. Bauerman thus describes the process as conducted in Styria: "The first portion of the charge, weighing 120 lbs., is melted down with a small quantity of cinder, the latter being strewed over the coals, the reheating of the blooms from the former operation, about ten or twelve in all, going on at the same time. When only two blooms are left, a further addition of pig iron is made to the extent of from 30 to 60 lbs., and the blowing is continued until the hearth is filled to within one or two inches of the tuyere. The fire is then allowed to go down quickly, the slag is tapped through a hole in the front plate into a trough filled with water, and the lump of crude steel remaining on the hearth is allowed to cool, out of contact with the air, by covering it with a shovelfull of moistened cinders. In about a quarter to half an hour, after stopping the blast, the lump is lifted out of the furnace, and is then divided under the hammer into ten or twelve pieces, which are reheated during the firing of the next charge. The bars

drawn under the hammer are hardened by quenching in cold water, and broken in order to test their quality. They are sorted, according to hardness, into several classes, distinguished by special names. The best are known as chisel or tool steel, Noble steel, and crude steel, below which come a variety of steely irons, used for scythe making, wagon-wheel tires, and similar purposes."

What is known as "puddled steel," made in furnaces differing very slightly from ordinary iron-puddling furnaces, was at one time largely produced; but this process also has, like the last-named, been superseded, so that I need not trouble you with a description of it. I believe, however, that it may still be seen in operation at the Birkenhead Forge. I have now to deal with the two processes which have, in recent years, created, and in fact, are still working out, such a great revolution in the iron and steel manufactures of the world. Before the invention and extensive adoption of the Bessemer and Siemens-Martin processes steel was a very costly material to purchase, and was produced in comparatively small quantities for special purposes, which were restricted within very narrow limits. Now, we have works in this kingdom alone equal to a production of something like 1,000,000 tons of Bessemer, and 400,000 tons of Siemens steel per annum; and the use of the products of these processes is becoming every day more extensive and varied. The railways of the world are now largely made of these metals, as are also large and increasing portions of the engines, carriages, and wagons, which run upon them. The same may be said of the ships of the Royal and merchant navies, together with their engines and boilers. Not only in the arts of peace do we find the use of steel largely and rapidly extending, but also in that of war; for not only are rifles made of it, from the barrel to the striker-needle, but likewise in the construction of guns of heavy caliber, the shell to be fired from them, the carriages on which they are placed, the racers or railways on which they are mounted and trained, and even the armor plates of vessels at which they may be fired. Steel is now rapidly taking the place of iron. If, then, it were interesting to you to know something of the older and more limited methods by which steel has been and is still produced, much more important is it that you should have knowledge regarding those more modern and extensive processes by which they are being replaced. Mr. Bessemer startled the metallurgical world, in 1856, by the statement that he had invented a method of manufacturing malleable iron and steel without fuel. In the paper which he read before the Mechanical Section of the British Association at the Cheltenham meeting in that year he proposed to accomplish this by treating liquid pig iron, which had been melted in a cupola or reverberatory furnace, or even been taken direct from the blast furnace, in a special apparatus, by which thin jets of atmospheric air were forced through the liquid metal. No fuel was used or needed in the process, as the temperature was maintained, and even increased, by the combustion of the carbon, and also by the oxidation of part of the iron. Thus, by the oxidation of the carbon, it was so far reduced that the resulting product was either liquid steel or wrought iron.

You will, doubtless, be struck by the modest extent of Mr. Bessemer's first patent. It is simply a modification of the "coke-hole" furnace already described. The crucible is similar, except that provision is made for tapping the metal out into the ingot mould beneath; also that the cover is altered in form and perforated, so that the gases generated may escape. Through the center of the cover a pipe passes down into the fluid metal conducting the air blast, which is forced through holes at its lower extremity into the fluid metal. From such small beginnings, and such simple means have grown the grand and striking operations of to-day, conducted in the imposing apparatus which Mr. Bessemer afterwards designed, and which gave completeness to his invention. The converters are usually worked in pairs, one being repaired or changed, whilst the other is in full use. They are pear-shaped in form, and are of different sizes, some now being able to take a charge of 15 tons weight, although the most common weight of charge is from 7 to 10 tons. They are suspended on trunnions, and provided with machinery, by which they

can be rotated vertically through an angle of 180°. The outer casing is made of wrought iron riveted together; the lining is made of very refractory materials, gannister being mostly used for this purpose, the tuyeres are peforated by parallel holes about $\frac{5}{8}$-inch diameter, and from seven to twelve in number, and through them the blast is forced into the metal, after having passed through one of the trunnions, which is made hollow, into the wind box under the tuyeres. The blast has a pressure of from 20 to 25 lbs. on the square inch. The ladle carriage is arranged so that it can be raised and lowered, as well as made to revolve on its axis, like a railway turn-table; thus it can be lowered to recieve the charge from the converter, then passed out from under the vessel, and afterwards over each ingot mould in succession. The machinery for moving the converters and the ladle carriage is worked by hydraulic power, and is controlled by one man placed at a little distance, where he can clearly discern and govern the whole of the operations, including the admission of blast to the vessels. I hope I have given you an idea of the machinery of the Bessemer pit, and will now proceed to describe to you the manner in which the process may practically be carried into operation, and I do this in the words used by Mr. Bessemer, in a paper read before the Institution of Civil Engineers, in 1865.

"The vessel, having been heated, is brought into a horizontal position, so that it may receive its charge of melted metal without the tuyeres being below the surface. No action can therefore take place until the vessel is made to assume the vertical position. The process is thus, in an instant, brought into full activity, and small though powerful jets of air spring upward through the fluid mass. The air expanding in volume divides itself into globules, or bursts violently upwards, carrying with it some hundredweights of fluid metal, which again fall into the boiling mass below. Every part of the apparatus trembles under the violent agitation thus produced, a roaring flame rushes from the mouth of the vessel, and as the process advances, it changes its violet color to orange, and finally to a voluminous pure white flame. The sparks which at first were large, like ordinary foundry iron, change to small hissing points, and these gradually give way to soft floating specks of blueish light as the state of malleable iron is approached." "Thus, by the mere action of the blast, a temperature is obtained in the largest masses of metal in ten or twelve minutes, that whole days of exposure in the most powerful furnaces would fail to produce." "The changes in the color and volume of the flame, and the kind of sparks thrown off, afford easy methods of judging of the state of the metal. The sound which the metal produces in the suspended vessel affords also a good indication to the workman. Indeed, few processes appeal so strongly to the external senses. When the desired quantity of air has passed through the metal, the vessel is turned on its axis, and the fluid steel is poured out. It is then received in the casting ladle, which is attached to the arm of an hydraulic crane so as to be brought readily over the moulds. The ladle is provided with a fireclay plug at the bottom, the raising of which, by a suitable lever, allows the fluid steel to descend in a clear vertical stream into the moulds. As soon as the first mould is filled, the plug valve is depressed, and the metal is prevented from flowing until the casting ladle is moved over the next mould when, by raising the plug, the second mould is filled in like manner, and so on until all the moulds are filled. After the discharge of the vessel the process should be repeated without delay, since the temperature of the vessel is greater after the first charge than it was before, and, consequently, it is in a better condition for the process. Thus, by the control of one responsible man, charges of several tons of crude cast iron may be converted into malleable iron, or into steel, in a few minutes, and be cast into ingots of any desired form and weight, suitable for larger shafts, or for rolling into rails, merchant bars, or plates.

Such is the Bessemer process, and it can scarcely be wondered at, that when the inventor first made it public, "his proposition was (to use his own words) almost generally looked upon as a chimera, or, as the mere day dream of an enthusiast, which the quiet, everyday practical man felt bound to disbelieve,"

although the laws on which the whole theory of his invention was based were well known; and hence the process was recognized from the very first by many of the scientific men of the day. The history of Mr. Bessemer's early difficulties, and how they were gradually, one by one, overcome; of how he determined, in spite of the opinions loudly expressed against the process, to pursue an undeviating course, and to remain silent for years under the scepticism of those who predicted its failure, rather than again to bring forward his invention until he had himself practically and commercially worked the process. I say this history is one of deep interest, and calculated to excite within us great sympathy for him in his earlier efforts and failures, as well as admiration of the patience and perseverence he exercised under them, and the powers of mind and fertility of resource manifested throughout. There had been long an idea that steel might be made on the open hearth of a furnace, before Dr. Siemens furnished the means of its accomplishment by the application of the regenerative gas furnace to this end. Of all the plans with this object, that proposed and patented by Heath in 1845, was the first. He conceived that cast steel might be produced by fusing wrought and cast iron together on the open hearth of a reverberatory furnace. The wrought iron was to be placed in a separate part of the furnace between the fluid metal and the chimney, and, having been there heated by the waste heat of the flame, was to be pushed forward into the bath in order to be dissolved. Heath proposed to heat his furnace by jets of gas, fearing the effect of the ashes from a common fire place. This process gave great promise of success, but failed from want of ability to obtain the necessary intensity of heat, and to control sufficiently the action and character of the flame.

I pass by other proposed modes of working to mention that known as the Siemens-Martin process. It is now about twenty years since Dr. Siemens—having, in conjunction with his brother, patented the regenerative gas furnace—first directed his attention to the melting of steel in pots and on the open hearth. His improvements on the ordinary crucible furnace I have already described, but when doing so I passed over the means devised for obtaining the gaseous fuel—a most essential and important part of all his inventions. This is known as the Siemens gas producer, which has been described as follows: "A brick chamber, perhaps 6 feet by 12 feet, and about 10 feet high, has one of its end walls converted into a fire grate, *i. e.*, about half way down it is a solid plate, and for the rest of the distance consists of strong horizontal plate bars, where air enters; the whole being at an inclination such as that which the side of a heap of coals would naturally take. Coals are poured through openings above upon this combination of wall and grate, and being fired at the under surface, they burn at the place where the air enters; but as the layer of coal is from two to three feet thick, various operations go on in those parts of the fuel which cannot burn for want of air. Thus the upper and cooler part of the coal produces a large body of hydro-carbons. The cinders or coke which are not volatilized, approach in descending towards the grate. That part which is nearest the grate burns with the entering air into carbonic acid, and the heat evolved ignites the mass above it; the carbonic acid passing slowly through the ignited carbon becomes converted into carbonic oxide, and mingles in the upper part of the chamber (or gas producer) with the hydro-carbons. The water which is purposely introduced at the bottom of the arrangement, is first vaporized by the heat, and then decomposed by the ignited fuel, and rearranged as hydrogen and carbonic oxide, and only the ashes of the coal are removed as solid matter from the chamber at the bottom of the firebars."

In the lecture which Dr. Siemens recently delivered here, he described an improved form of gas producer which seems to give promise of many useful improvements on the one now in general use, and which I have just referred to. Professor Faraday thus lucidly described the Siemens open-hearth regenerative furnace: "The gas from producers rises up a large vertical tube for 12 or 15 feet; after which it proceeds horizontally for any required distance, and then descends to the heat regenerator, through which it passes before it enters the furnace. A regenerator is a chamber packed with

fire bricks, separated so as to allow of the free passage of air or gas between. There are four placed under a furnace. The gas ascends through one of these chambers, whilst air ascends through the neighboring chamber, and both are conducted through passage outlets at one end of the furnace, where, mingling, they burn, producing the heat due to their chemical action. Passing onward to the other end of the furnace, they—*i. e.*, the combined gases—find precisely similar outlets, down which they pass; and traversing the two remaining generators from above downwards, heat them intensely, especially in the upper part, and so travel on in their cooled state to the shaft or chimney. Now, the passages between the four regenerators and the gas and air, are supplied with valves and deflecting plates, which are like four-way cocks in their action, so that by the use of a lever those regenerators and airways, which were carrying off the expended fuel, can, in a moment, be used for conducting air and gas into the furnace; and those which just before had served to carry air and gas into the furnace, now take the burnt fuel away to the stack. It is to be observed that the intensely heated flame which leaves the furnace for the stack always proceeds downwards through the regenerators, so that the upper part of them is most intensely heated, keeping back, as it does, the intense heat; and so effectual are they in this action, that the gases which enter the stack to be cast into the air are not usually above 300° Fah. of heat. On the other hand, the entering gas and air always pass upwards through the regenerators, so that they attain a temperature equal to a white heat before they meet in the furnace, and then add to the carried heat that due to their mutual chemical action. It is considered that when the furnace is in full order, the heat carried forward to be evolved by the chemical action is about 4,000°, whilst that carried back by the regenerator is about 3,000°, making an intensity of power which, unless moderated on purpose, would fuse furnace and all exposed to its action. Thus the regenerators are alternately heated and cooled by the outgoing and entering gas and air; and the time for alteration is from half an hour to an hour, as observation may indicate. The motive power on the gas is of two kinds; a slight excess of pressure within is kept up from the gas producer to the bottom of the regenerator, to prevent air entering and mingling with the fuel before it is burnt; but from the furnace downwards through the regenerators the advance of the heated medium is governed mainly by the draught in the tall stack or chimney.

As in the case of Sir Henry Bessemer, so again in that of Dr. Siemens, the difficulties and disappointments which attended his efforts to introduce his process and secure its adoption by manufacturers were such as would have daunted and overcome a less resolute spirit; but here, again, there is the same confidence that success is possible, combined with the determination that it shall be achieved, and the necessary powers of mind and of resources to justify both the confidence and determination. The result of his labors is manifest in the high estimation in which his process is now generally held, especially where finer qualities of steel are required for purposes where uniformity and regularity in the product are of vital importance. Dr. Siemens states that, "having been so often disappointed by the indifference of manufacturers and the antagonism of their workmen, I determined in 1865 to erect experimental or 'sample steel works' of my own at Birmingham, for the purpose of maturing the details of these processes before inviting manufacturers to adopt them. The first furnace erected at these works is one for melting the higher qualities of steel in closed pots, and contains sixteen pots of the usual capacity. The second, erected in 1867, is an open-hearth furnace, capable of melting a charge of 24 cwt. of steel every six hours. Although these works have been carried on under every disadvantage, inasmuch as I had to educate a set of men capable of managing steel furnaces, the result has been most beneficial in affording me an opportunity of working out the details of processes for producing cast steel from scrap iron of ordinary quality, and also directly from the ore, and in proving these results to others."

I have already given you a description of the furnace as used for steelmaking; but this is not sufficient for a full under-

standing of the *modus operandi* of the process. Let us suppose that we are commencing operations with a new furnace. This having been dried by means of a wood fire kept alight on the bottom or hearth, the gas valve closing the connection with the tubes of the gas producer, previously described, is opened to a slight extent, as also is the valve for closing the tube by which air is admitted; the reversing valves are fixed to direct the air and gas to one pair of regenerator chambers under the furnace; these are gradually passed through, and the air and gas are conducted through several flues until they meet at a given point in the furnace, when combustion take place, and the flame, passing slowly through, escapes by corresponding flues at the opposite end, and through the other pair of chambers to the chimney flue. I have already stated how the heat, which would otherwise become waste, is caught and stored up in the regenerator, and how—upon the direction of the currents of gas and air being reversed—this heat is taken up by them, and elevates their temperature to a very high degree, so that upon combustion taking place in the furnace, a heat of great intensity is obtained, and that at the exact point where it is most required and is of most advantage. Under this treatment the furnace is gradually made hotter, and the furnaceman commences to make the bottom. This is done by spreading thin layers of a selected sand over the brickwork of the bottom; each layer is fused before another is laid on, so that at last the surface assumes the form of a shallow basin, solid and impervious, and requiring only very slight repair after the working of each charge. The furnace being thus prepared, the pig iron, and heavier portions of the scrap, are charged into the furnace through the doors provided for the purpose; the furnaceman is careful to distribute his charge so as to obtain the greatest effect from the flame that it may be quickly melted, placing the scrap on the banks of the furnace where it may be thoroughly heated prior to being turned down to be dissolved in the bath of melted pig iron. After a time the whole of the pig is melted, the scrap is turned down, and smaller scrap is thrown in at intervals. During these operations the bath has become covered with a coating of slag, which tends to protect it from the action of the flame. This slag the furnaceman endeavors to "clean" as he terms it, that is, to free it from iron, by the addition of limestone or other fluxes. By and by the furnaceman inserts a long-handled spoon, and takes out a sample of the metal, which he cools in water, and aftewards hammers and breaks. By the behavior of this sample —its hardness or malleability, and by the appearance of the fracture—he judges of the stage at which the charge has arrived. After frequent samples taken he is satisfied as to the point of decarburization reached—then samples are submitted to the chemist, who finally passes the charge as being what is required. Thereupon a quantity of spiegeleisen or of ferro-manganese is, after being heated to redness, charged into the bath, and the whole is tapped out into the ladle. This is done by the insertion of a strong-pointed bar into the tap hole, which has been very carefully formed in the process of making the bottom, and closed with a special mixture before throwing in the charge. The ladle is suspended on a carriage, and various means are adopted for bringing it over each of the ingot moulds in turn, when, as in the Bessemer process, the steel is tapped out of the bottom of the ladle. The charges worked in the earliest furnaces weighed, as we have seen, about 25 cwt. each; now 10, 12 and even 16 tons are dealt with in one operation.

This is the Siemens-Martin process; but the Siemens process differs from it in some particulars. Very little scrap, sometimes none at all, is used; but the charge consists mainly or entirely of pig iron, which is placed on the bottom and round the sides of the furnace in the manner previously described. Melting requires four or five hours; then ore, of pure character, is charged cold into the bath, at first in quantities of four to five cwt. at a time. Immediately this is done a violent ebullition takes place; and when this has abated, a new supply of ore is thrown in—the object being to keep up uniform ebullition as nearly as may be. Of course, care is taken that the temperature of the furnace is maintained so as to keep the bath of metal and slag sufficiently fluid; but after the lapse of some time, when the ore is thoroughly heated, and

reduction is taking place rapidly, the gas may be in part shut off the furnace, the combustion of the carbon in the bath itself keeping up the temperature. In the course of the operation, the quantity of ore charged is gradually reduced, and samples are taken from time to time of both slag and metal; when these are satisfactory, spiegeleisen or ferro-manganese are added, and the charge cast as in the previous case. This mode of working takes rather more time than the scrap process, and the consumption of fuel is rather larger; but it has this advantage, that there is greater certainty as to the result, because of the known composition of the materials charged, which can not be the case in dealing with large quantitities of scrap obtained, it may be, from a thousand sources. Then, again, the loss on the pig by the removal of its silicon and carbon is about compensated by the iron obtained from the ore, which has been used to furnish the oxygen for decarbonization.

There is another form of open-hearth furnace, known as the Pernot, which has been adopted at one or two works in France. The hearth is of circular form, is separated from the body of the furnace, and is supported on a movable carriage. It is also so arranged that it can be rotated on its axis, which is inclined at an angle of 5° or 6° to the vertical. In charging the furnace the pig iron, previously heated to redness in an auxiliary furnace, is placed on the bottom, with the whole of the scrap over it. The bed, or hearth, is then made to revolve slowly, and each piece of scrap is alternately exposed to the full heat of the flame, and dipped in the bath of metal which soon begins to form. The fusion is thus very rapid—the whole charge of about five tons—is fluid in about two hours. Samples are then taken out at intervals, and when the metal is sufficiently soft spiegel is added, and the charge is tapped out. It will be seen that in this system also the regenerative system is adopted, the form and positions of the chambers and the ports, or flues, being modified to suit the other portions of the arrangement. When repairs are necessary, either to the bed, or roof, or ports, the carriage is withdrawn so that these may be done with greater ease and with less loss of time. Two of these furnaces have been erected at Blochairn Works, and have been under trial for some time; but at present I am not able to state that there is any balance of advantages in their favor when compared with the modern Siemens furnaces working alongside them.

If you think for a moment on what I have said, you will no doubt perceive that up to this point my sole aim has been to make you acquainted with the different processes by which steel is manufactured, and with the machinery and apparatus used in each; also, that I have hitherto almost disregarded both the raw materials used, and the quality of the resulting product. I set out with the statement that steel is an ally of iron and carbon, and up to the present have directed your attention simply to the means of obtaining this alloy with the desired proportions. As you are aware, good wrought iron has the properties of malleability and ductility to a large extent, and its tensile strength is considerable. Now the addition, within certain limits, of carbon to iron, has the effect of reducing its malleability and ductility; but its tensile strength is increased, and it acquires the property of hardening and tempering when, after being heated, it is suddenly quenched in cold water. I have said that this is the case when carbon is added within certain limits, and it will probably astonish you to know how narrow these limits are; thus, steel attains its greatest tensile strength when only about one per cent. of carbon is present, when it has an elastic limit of about 30 tons, with an ultimate tensile strength of about 60 tons on the square inch of sectional area; but this steel has but little ductility, and is comparatively brittle, hence it is not adapted to the wants of the engineer for constructive purposes, although it may be well suited to other requirements. From this you will perceive that it is necessary for the steelmaker to vary his practice, at one time supplying steel with not more than 1-1000 lbs. per cent. of carbon, having a low tensile strength, but great ductility, as in the sample before you. Next, he is called upon to supply steel for boilers and ships, which shall come within strictly specified limits as to strength and ductility, and the carbon will be 0.15 to 0.20 per cent. Then he may

have to give a steel for structural purposes, with a higher breaking strain, but necessarily less ductility, and the carbon may be increased to, say, 0.3 to 0.35; or, again, a harder steel may be required, especially prepared to resist wearing action without sacrificing strength, &c., as in rails and tires, and the carbon becomes 0.4 to 0.5 per cent.; but still the catalogue is not exhausted, and the maker is called upon to furnish steel with all shades of temper due to carbon between this point and up to 1.25 per cent.

Now, this would be comparatively easy of accomplishment if it always followed that, given the iron and carbon, the tests proposed would be satisfied; but, unfortunately, there may be phosphorus present, when the brittleness of the steel is increased largely, and its ability to withstand a blow greatly impaired. The steel is, consequently, unfit for its purpose, although it has the qualities of working well through the different operations by which it is changed from an ingot to the finished product. Then, again, there may be sulphur present, and what is called "redshortness" results, that is, the steel cannot be forged or rolled at all if it is present in considerable quanties, and only with great care and with imperfect results if only in moderate proportions. If the operations are completed, however, it does not appear that sulphur has any deleterious effect, but possibly may slightly increase the strength of the steel, as it does when present in cast iron. Again, silicon is sometimes found in the steel, and may have been in excess in the iron used, and the resulting quality will be very unsatisfactory, or sometimes copper, and again, redshortness, will trouble the workmen. All these elements have been greatly objectionable to the manufacturer of steel, hence only the purest materials have been used, and the science of the chemist has been very largely called in to enable the manufacturer to choose rightly, and use judiciously, all the materials he requires. Now, Mr. Bessemer has told us that he was unsuccessful in his earlier efforts to produce good steel, because he endeavored to do this from ordinary pig iron; that he was successful when he used Swedish or other iron, free from impurity, and from this circumstance has sprung the great development of the manufacture of hematite pig iron, the purest made in this country, and the best qualities of which are known as No. 1, 2 and 3 Bessemer. These qualities are almost free from sulphur and phosphorus, but contain sometimes as much as five per cent. of silicon, which has been considered by makers of Bessemer steel rather an advantage than otherwise; because, in its combustion, the heat developed is very great, and useful in the working of the charge. For this reason, as well as because of its purity, grey pig iron—the greyness being in part due to silicon—is always used in the Bessemer converter, while in the Siemens process, a closer iron, say No. 3 and 4, is used; but it is always a stipulation that the silicon shall be as low as possible, and that the sulphur should not exceed 0.06, or phosphorus more than 0.05.

Regarding the latter element, however, the belief has always been held, since the make of steel attained such huge dimensions, that methods would be discovered by which it would be eliminated from the iron, and thus the immense deposits of phosphoric iron ores in this and other countries would be rendered available for steelmaking. The immense importance to those engaged in ironmaking of such a discovery naturally stimulated chemists and metallurgists to unwearied research and experiment, but it has been reserved to two young men, Messrs. Thomas and Gilchrist, to practically solve the problem. I cannot stop to fully describe their process, but would simply state that it depends for its success on the possibility of substituting a basic for an acid slag in either the Bessemer converter or the Siemens or other open-hearth furnace. Chemists would not experience any difficulty in producing this slag, with which the phosphorus in the molton iron would combine, and leave the iron practically pure; unfortunately, however, both the converter and the furnace were in all cases lined with acid materials, so that in vessels thus lined it was impossible to retain the basic character of the slag, on which everything depended. What Messrs. Thomas and Gilchrist have accomplished is, in addition to the production of a basic slag by certain specified means,

they have made bricks of basic materials, and of such character that the converters and furnaces may be lined with them, so that the character of the slag shall not be injuriously modified during the remainder of the operation. This discovery, although apparently of so very simple a character, is no doubt destined to produce a revolution in the steel manufacture of the world. I am not sure that, in this country, except in very special cases, it will enable those who use it to compete successfully with those using hematite iron, so long as the latter can be produced at a cost so nearly approaching that of phosphoretic pig iron; but I have no doubt that on the Continent, where phosphoretic pig can be produced in very large quantities and at a very low cost, and where hematite iron was either imported from this country or produced at a high comparative cost, the margin between the costs of the two different kinds of pig iron will enable those who adopt the new process not only to work at a considerable profit over their former practice, but also, by reducing the cost of the steel made, constitute them formidable rivals in their own and foreign markets, and make them independent of supplies of hematite pig iron from this country.

I must now refer to another element which plays an important part in the operation of the steelmaker, that is, the metal manganese. I have referred to "redshortness" as being due to the presence of sulphur in the steel, but Mr. Bessemer, like all other steelmakers since, was troubled with a redshortness in his ingots, due to another cause than the presence of sulphur—this was the presence of either oxygen or carbonic oxide in very appreciable quantities, locked up in small cells, giving the ingot the fault now known as being honeycombed. This defect threatened to be fatal to the process were not a remedy found. Now, some years before this, Heath had discovered the beneficial effect of manganese in the crucible process, and had taught the Sheffield steelmakers to use it either as oxide of manganese or in some carburetted form. They recompensed him by breaking his heart, through the constant litigation to obtain the reward due to his invention. More recently Mushet had patented the use of spiegeleisen, which contained varying quantities of manganese, and he suggested that by using this iron at the close of the blow, the manganese, being readily oxidizable, would combine with the oxygen forming the cells, or honeycomb, and so the difficulty would be got over. This was in fact the case, and from that time to this the alloys of iron and manganese have been constantly growing in importance. You will now understand why I said that the making of steel with a certain quantity of carbon could be easily accomplished—for it was only necessary to "blow" the metal to a certain point in the Bessemer process, or to dilute it, or to burn it out by charges of ore in the Siemens-Martin or Siemens process, until the iron was thoroughly decarburized, then to add a calculated quantity of spiegeleisen (which, with varying quantities of manganese, always contained a nearly uniform quantity of carbon), and the result was attained, if the operation was carefully conducted. But speigeleisen in those days contained only about 9 or 10 per cent. of manganese; and as it was found to be necessary that the steel should contain not less than 0.3 per cent. of manganese, this could not be added without so increasing the carbon that it was impossible to make what we now call soft steel, hence attention was at once given to the manufacture of spiegel as rich in manganese as possible. This was accomplished so far, that as much as 30 per cent. of manganese was obtained. But the manufacture has been carried to a higher pitch in the production of ferro-manganese, where the manganese present has been increased to even 80 per cent. Thus the means of increasing the manganese in his steel without adding to the carbon, or of decreasing the carbon without losing his manganese, was placed in the hands of the manufacturer; and it was rendered possible to produce the remarkably fine qualities of soft steel which have been made in recent years, of which specimens are before you. Thus, manganese is of very great use to the steelmaker, and when used in combination with silicon and iron in the form of the alloy now before you, it enables us to produce the very fine castings which are to be found in this exhibition. This alloy is the invention of the Terre Noire Company in

France, who have made great use of it in the production of fine castings of large size in the shape of marine engine shafts, &c. Their process in the hands of the Steel Company, who are applying it to the production of the various parts of engines, stationary, locomotive, and marine, and to many other important requirements of engineers and others.

Manufacturers were not slow to avail themselves of the opportunity thus afforded them, and the result has been the immense development in the production of "mild steel" or "ingot iron," to which I referred in my opening remarks. Naturally the fitness of this class of steel for ships and for boilers was at once recognized. Having greater tenacity than the best Yorkshire iron, with as large an amount of ductility, also having this higher tenacity nearly equally in all directions of the plate, steel at once commended itself to the boiler maker. The use of steam at higher pressures for marine engines was made increasingly possible. Engineers had already reached the limit it seemed possible to attain while using iron, for plates were now 1¼ inch thick in iron. As it was possible to have a boiler of the same strength as iron, with the scantlings of steel reduced 25 per cent., it is evident that by retaining the same scantlings in steel the pressure might be very largely increased without any increase of risk to safety, or of difficulty in construction. Then, again, it was recognized that if advantage was taken of the superior strength of steel to reduce the thickness of the internal plates of boilers, the increased steam-generating power would be very valuable and useful. Further, in practice it has been found that although steel is much higher in price than common iron, it is much lower than Low Moor or best Yorkshire iron, and that when all the facts of the case are fully considered a boiler may be built of steel at about as low a first cost as one built in the ordinary style of iron. Then, again, the boiler maker has found that he has less trouble with the defective plates when using steel, and this is an important matter to him. It is, then, no wonder that the use of steel for this purpose has very largely developed; and I have the authority of Mr. Parker, of Lloyds' *Registry*, for stating that, with the exceptional case of the "Livadia's" boilers, out of all the thousands of tons of steel boilers which have come under their survey, they have not had one single case of failure or of trouble. There have been cases when, in the course of construction, plates have been torn or cracked, but he states that in every case the cause is known, and cannot be charged against the qualities of the steel used.

The British Admiralty led the way in the "new departure" in shipbuilding so far as this country was concerned; and, in connection with the supply of the material for the construction of the "Iris" and "Mercury" for the Admiralty, I had the honor of reading a paper before the Institute of Naval Architects in London, in which the qualities of the metal were described, and its behavior under various tests indicated. Mercantile owners, however, were very slow to patronize the "new metal," and I well remember the anxiety I then experienced to obtain a contract for the supply of steel for a merchant vessel. This was at last accomplished in Newcastle. The ice was thus broken, but progress was disappointingly slow. The Admiralty followed up their first venture by contracting for six corvettes to be built of steel by Messrs. Elder & Co. The owner of the merchant vessel to which I have referred had such satisfactory returns from her, that he contracted for a second vessel. Meanwhile, the use of steel had been engrossing more and more of the consideration of shipowners and builders, and many small ventures were made, until at length the great companies took the matter up. Messrs Allan led the way with the "Buenos Ayrean," and were quickly followed by the Pacific Steam Navigation Company, Mr. Donald Currie, the Peninsular and Oriental Company, the British Indian Company, the White Star Company, the Cunard Company, the Orient Company, and many others, the latest and grandest of the vessels built of steel being the "Parisian" and the "Servia," launched the other day into the Clyde. I have already named the small quantity of steel which sufficed for the requirements in 1878. It has been stated that in the following year 19,000 tons of steel vessels were launched on the Clyde alone, while last year the tonnage was increased to

43,000 tons. We claim that vessels built of this mild steel are much safer than those built of iron; that there is less risk of loss with them; and we therefore contend that they ought to class higher, and ought to be insured at lower premiums; also that, being lighter, because of the reduction of scantling allowed as compared with iron, their earning power—especially when carrying deadweight cargo—is so much increased that they make very handsome returns for the additional first cost due to the use of steel.

In support of my statement that steel vessels are safer, I might quote many cases where they have withstood trials that would probably have seriously injured iron ships in similar circumstances, but I content myself with referring to two striking instances. The photograph before you shows the steel plates cut out of the "G. M. B.," a vessel belonging to Messrs. James Watson & Co., of this city, after she had been in collision at sea. You will see that they are bent and crumpled up in fearful style, yet not one is cracked. It was the opinion of experts who saw her after the collision that had she been built of iron she must have inevitably sunk. The other is a more striking instance, and was related by Mr. Wm. Denny, of Dumbarton, to the Institute of Naval Architects: "The 'Rotomahana' had a very narrow escape from total loss on 1st of January. She was engaged in an excursion from Auckland to Great Barrier Island, a distance of fifty miles, and was leaving the harbor of Fitzroy (in Great Barrier Island) by a somewhat difficult passage, when she struck on a sunken rock with considerable force. She made some water on the way back to Auckland, as it afterwards turned out, through some rivet holes; these were plugged, and she was enabled to return to Dunedin to be docked. The enclosed report from our marine superintendent will explain the nature of the damage. The worst damaged plate was taken out, re-rolled and replaced. Several frames were set back, and a good job made of the repairs within seventy-two hours. This experience has shown clearly the immense superiority of steel over iron. There is little doubt that, had the "Rotomahana" been of iron, such a rent would have been made in her that she would have filled in a few minutes. A number of frames were set back by the force of the blow; the bulkhead was bulged, and the plate was corrugated, and yet there did not appear one crack anywhere."

Mr. A. Cameron, marine superintendent, thus reported on the case: "On examining the bottom it was found that, on the starboard bilge, at the bulkhead, between the forehold and the stokehole, about 20 feet of the fourth strake from the keel, was all more or less indented; one plate particularly, 14 feet by 3 feet 7 inches by $\frac{1}{2}$ inch thick, being very badly indented between the frames. This plate we decided to remove, and started doing so at 7 P. M. on the 7th instant. The removal occupied twenty-four hours, as all our tools broke in the work, and a new set had to be specially made to stand the steel. The plate looked so bad that it was doubtful whether it was worth while spending any time over it, however we decided to give it a fair trial, and it was put in the furnace, and heated for two hours, then taken out and hammered on the blocks. This process had to be repeated three times before the rollers would take it in, but when it had passed through the rolls, it really looked like a new plate, perfectly sound and good. In working it stretched $\frac{3}{16}$ths of an inch, but by paring a little of the ends, the rivet holes, at both the landings, and the butts came in exactly as required for a true fit. Seven of the frames were badly bent, with a sharp curve tending both inwards and aft, two being bulkhead frames, with double angles, and very strong. The floors were cut, and the frames thoroughly examined, but we found no sign of crack or strain in the material. The frames were heated and re-straightened, and riveted to the floors. All the riveting was completed by 6 P. M. on the 10th instant. It may be here stated that, had the frames been composed of iron, instead of the splendid ductile material of which they are composed, they would all require to have been renewed; and, even then, they would not have made such a complete job as the present.

But what are the alleged disadvantages of the use of steel? First, that its cost, as compared with iron, is too great. This objection was a formidable one

when plates were sold at nearly £20 a ton, but since then constant and unremitting efforts have enabled steelmakers to reduce the price within such limits as may be called reasonable, and will enable the vessel to earn a good return on the increased expenditure. Doubtless the increased competition due to the rapid extension of steel works will sharpen our wits, and compel us to adopt, or to find out, means of producing at a lower cost, that so the demand may be sufficiently increased to find occupation for us all. I am informed that there will be built this year, under Lloyd's survey alone, something like 700,000 tons of shipping, requiring in its construction from 250,000 to 300,000 tons of iron or steel, and although this may be an exceptional year, yet it will not be for want of great exertions on the part of steelmakers if they do not obtain a due share of orders, which are sufficiently large to employ at least six times the power of production possessed by the Steel Company of Scotland. Then it is stated by some inexperienced people that steel is more difficult to work in the shipyard. Against that I may quote the testimony of those who have used steel most extensively. Messrs. Denny, who have had contracts requiring 18,000 tons of steel, inform me that their men prefer working steel rather than iron, and that if they could obtain contracts for steel vessels, sufficient to keep their yard full, they would not build another iron vessel. Further, it is stated that steel vessels, being built with reduced scantlings, want stiffness. Now, this being the result of unsuitable designs, the metal not being properly distributed, it is evident that the skill of our naval architects will quickly remedy that defect, if it exists in reality, and not in the imagination of the hypercritical only. Then a great deal is said about corrosion. But this cry of the liability of steel to excessive corrosion, if not raised, has been greatly magnified by our friends, who, by the animus evident in what they say and write, appear to indicate that they are not particularly disinterested in their statements. A great deal has been made of the case of the "Iris," which the Admiralty have had examined; but I have it on undoubted authority that the case has been greatly exaggerated, and that the officials at the Admiralty had experienced no uneasiness or alarm in regard to her condition. As positive evidence against the statements as to corrosion, I can refer to many instances in which the anxiety of owners have led to careful examinations of ships and boilers built of steel, without discovering any trace of corrosion or pitting. I feel, therefore, that I am warranted in speaking strongly against the efforts being made to damage the character of steel in this respect.

Now I come to consider what appears to be the most serious charge of all. It is fashionable amongst a certain class to talk of the "mysterious behavior of steel" —to shake the head, shrug the shoulder, look wise and serious, and talk of its "unreliable character," "its utterly untrustworthy qualities," in strains which make the inexperienced feel that the less they have to do with steel the better. Now for a long time we have accepted all this condemnation as meekly as might be; we have occasionally ventured to express our opinion that unwarrantably hard things were being said of steel, that we hoped all was not true that was said, or at least that the statements were somewhat exaggerated.

We have endeavored by careful work to prevent accumulation of evidence on the part of accusers, have "bided our time" until the use of steel should be greatly extended and until the people using it should be greatly increased in number. I think the time has now come when we can assume a different attitude, and, allowing our enthusiastic feeling with regard to steel to have full sway, say to the detractors "Upon you lies the onus of proof" that steel is unreliable in character and untrustworthy in use as compared with iron. We direct you, in refutation of the statement, to the rigid character of the tests we undergo while anything that will hold together in the shape of iron may be put into a ship. We ask you to note the extremely few failures which have occurred in steel, in the shipyard, and contrast it with the failures in iron. I remember that when nearly 7000 tons of steel had been used in one of our shipyards not more than three plates had failed in working, and it was admitted that in two of these no fault could be found with the metal;

while in the same yard a small vessel was being built requiring about 40 tons of iron, and I saw not less than seven plates which had failed in working. During the time that Lloyds insisted upon rigidly testing steel in the shipyards instead of at makers' works, the total rejection of plates, &c., for not satisfying the required rigorous tests was very small indeed, and those which were so rejected were very much superior in quality to the iron in common use. Why, then, should we steelmakers submit to this stigma being attached to our production? We know that although there may be some few exceptional failures, yet they form an infinitesimal portion of the very large whole of our make; the metal which we send out of our works is worthy of the utmost confidence, and justifies the pride with which we refer to its many good qualities.

I have long felt very strongly on this point, and although it has not, I am happy to say, fallen to the lot of my company to have many complaints as to the quality of their productions, but rather the reverse, I have felt that scant justice has been done to makers of "mild steel," who have spared no expense or care in their efforts to achieve the success at which they have arrived, and who have sought for and made use of all the knowledge, scientific and practical, which was within their reach.

ENERGY EXPENDED IN THE MAGNETIZATION OF IRON.

By A. NIAUDET.

Translated from "l'Electricien."

The heating of an iron bar that is rapidly and repeatedly magnetized and demagnetized is a familiar fact.

It was specially noted by Siemens when he first employed his rotating armature between the poles of a permanent magnet.

If the alternating current from an Alliance machine be passed through a helix, within which is placed a small piece of iron, the latter heats rapidly. In view of this fact, we are led to inquire whether the heat is produced at the moment that the magnetism is excited, while it continues, or at the instant it ceases.

A permanent magnet may be compared to a coiled spring. A certain amount of force is necessary to coil the spring; it is equally necessary in charging the magnet. It is manifest that a magnet possesses a certain amount of energy; it is capable of raising its armature, and with it a certain amount of weight; but while sustaining the weight it is incapable of exerting this force anew. It is like the spring uncoiled. If the armature be detached the work previously performed by the magnet must be performed in the inverse direction, and the capacity of the magnet to attract is restored. It resembles the spring rewound. During the intermediate period the armature is held at rest; there is no expenditure of work.

Now, considering the case of an electro magnet, it appears *a priori* evident that the expenditure of a certain amount of energy is necessary to produce the magnetism. But when once produced is any expenditure necessary to maintain it? And, finally, when the magnetism ceases what becomes of the energy?

Experiment affords replies to these questions.

Establish two derived circuits, having equal resistances, so that the partial currents shall be equal, and so that their equality shall be established by a differential galvanometer. If one of these circuits contains a helix, and a bar of iron be inserted, the equilibrium between the derived currents is immediately disturbed. An increased resistance is exhibited in the current which has been made to encircle the iron rod. But the disturbance is only temporary; the galvanometer again returns to zero, and proves the restoration of equilibrium. This experiment indicates an expenditure of energy in the *production* of the magnet, but it proves also that no expenditure is necessary to *maintain* the magnetism after it is once produced.

There is evidently no difference be-

tween the two currents, one of which maintains the magnetism of a bar of iron, while the other does not. The expenditure of energy in the cases is the same, and it costs nothing to maintain the magnetism. In both cases the effect is entirely calorific.

But it must be observed that if the current ceases the magnetism disappears; consequently the maintenance of the electro-magnetism demands an expenditure of energy which can be calculated when the resistance R of the coil about the bar, and the intensity I of the current, are both known. It is equal to RI^2.

The above explanation may be illustrated by a mechanical example: A kite requires no expenditure of work so long as it remains at the same height; but if the wind suddenly ceases the kite falls, and so proves that it only maintains its place in the air by a certain amount of work of the wind.

M. Ayrton communicated to the Société de Physique, in January last, the result of some experiments upon the above phenomena. He made use of a highly intense magnetizing current; he took the precaution to pass a current of water, of constant temperature, through the annular space between the wire coil and the iron core; he employed for the temperature a thermopile of great sensibility. He never detected the least heating of the iron as a consequence of maintaining the magnetism of the iron.

The third phase of the phenomena, the cessation of the magnetism, remains to be examined. We have seen that the magnet absorbs energy at the moment that it is magnetized. What becomes of this energy when it is demagnetized? It seems indisputable that it must appear in the form of heat, and we find in this fact the explanation of the phenomenon mentioned in the beginning of this article—the heating of a bar when it was magnetized and demagnetized rapidly a great number of times.

Now applying these principles to the study of dynamo-electric machines, we see that during the short period required for the magnetic charge, there is an expenditure of energy corresponding to the production of the magnetism.

During the regular working of the machine there is no expenditure of work for the maintenance of magnetism, so to speak; but there is actually an outlay of calorific energy in urging the current through the coil of wire; an expenditure measured by the formula $\frac{RI^2}{9.81}$ kilogram-meters. The period of demagnetization is without interest.

The above remark supposes the current constant. If it is periodically variable, there will be an expenditure of work each time that the magnetic charge is raised from its least value to its greatest.

The current of the Gramme and the Hefner Von Altneck machines is undulatory, and would be absolutely constant only when the number of the sections of the coil became infinite. But practically when the Gramme ring is composed of sixty sections, the current may be considered as constant, and the variations caused in the magnetism of the electro magnets may be neglected.

ELECTRIC RAILWAYS AND TRANSMISSION OF POWER BY ELECTRICITY.

By ALEXANDER SIEMENS.

From the "Journal of the Society of Arts."

When electricity was first utilized for practical purposes, the cost of producing it precluded its application to anything but giving signals or working small and delicate apparatus, requiring only weak currents to perform their functions; but by the discovery of the dynamo-electric principle, some fourteen years ago, powerful electric currents have been placed at our disposal, at a cost which enables us to transform into commercial processes a number of experiments which, up to that time, served only as illustrations of scientific lectures.

The machines which have caused this

revolution in the application of electricity consist essentially of two parts—the fixed electro magnets, by which a powerful magnetic field is created, and the revolving armature, which is connected with the commutator. When the machine is in action, the rapid motion of the copper wire through the magnetic field induces an electric current, which leaves the helix by the brushes pressing against the commutator on opposite sides. From the brushes the current passes to the electro magnets, and afterwards to the outer circuit, where it has to perform the useful work. In traversing the coils of the electro magnets, it increases the intensity of the magnetic field, which in its turn induces a more powerful current, and this mutual strengthening of current and magnetic field goes on until a balance establishes itself in the manner afterwards described.

The researches of Sir William Thomson, Dr. Hopkinson, Professor Ayrton, and others have proved that such machines, if properly constructed, will render in the form of electrical work up to 90 per cent. of the energy expended upon them in the form of motive power. It may, therefore, be conceded that they are very efficient transformers, and that we can hardly hope to exceed the results already obtained by the best types of dynamo-electric machines. If, instead of using such a machine to generate electricity, you send a current into it, the magnetic attraction created between the poles of the electro magnets and the currents traversing the armature will cause the latter to rotate, and this motion can be communicated to other machinery in the usual ways. A pair of such machines, one for producing electricity and the second for re-transforming the current into motive power, can, therefore, be utilized for transmitting power to a distance. In order fully to understand the manner in which this transmission is effected, a large number of experiments were made at the works of Messrs. Siemens and Halske, in Berlin, by Dr. Frölich, and the results obtained were laid before the Royal Academy of Science, in Berlin, by Dr. Werner Siemens, on the 18th November, 1880.

The principal conclusions arrived at were the following: On applying Ohm's law to a magneto-electric machine (a machine with permanent magnets) we find that the strength of current for a given total resistance is:

$$(1) \qquad C=\frac{n\times M\times v}{R}$$

In this formula C signifies the strength of current; n, the number of convolutions of wire on the armature; v, the number of revolutions per minute; R, the total resistance in circuit; M, the total E. M. F. produced by the permanent magnets and the iron of the armature in one convolution of wire, when $v=1$; this quantity will afterwards be called "effective magnetism" of the machine.

The same formula holds good for a dynamo-electric machine. In this case, however, the "effective magnetism" (M) depends on the strength of current (C), and the formula, by substituting f (C) for n (M), becomes:

$$(2) \qquad C=\frac{vf(C)}{R};\ \text{or}\ \frac{C}{f(C)}=\frac{v}{R}.$$

In the latter form, the very important law is expressed that the strength of the current in a given dynamo-electric machine depends only on the ratio of the number of revolutions per minute to the total resistance in circuit. If we determine, therefore, f(C) for a machine, we can calculate beforehand the strength of current it will produce with a given number of revolutions in a given resistance.

The first series of experiments was made to test the correctness of this conclusion, and the curves I., II., and III., embody the results obtained by working one of the largest "Siemens'" dynamo machine (type D_s.) through various resistances at different speeds. The total resistance of the machine was, in case (I.), .435 S. U.; in case (II.), .725 S. U.; and, in case (III.), .714 U. S.

By way of comparison, the curve IV. was set out from results published by Messrs. Meyer and Auerbach in "Wiedemann's Annalen," Band 8, p. 494, who had experimented with a "Gramme" dynamo machine. As will be seen, all these curves do not differ materially from a straight line, and, for the limits of practical working, they fully confirm the above theory. There exists, therefore, a curious similarity between magneto-elec-

tric and dynamo-electric machines. In both, the strength of current is proportionate to the ratio of revolutions per minute to total resistance, although the magnetism of the magneto machines is a constant quantity, and that of the dynamo machines varies with the strength of current. The important difference between the two kinds of machine is, that magneto machines give a current however slow their motion is, whereas dynamo machines only begin to give a current when the ratio of number of revolutions to total resistance attains a certain magnitude.

The nature of the $f(C)$ was then further examined, and the influence on the magnitude of the "effective magnetism" of the currents set up in the iron of the armature by its quick rotation in a magnetic field, and by the currents traversing the coils of the armature. The results arrived at are represented by the curves V., VI., VII., for the large Siemens machine, and by the curve VIII. for the Gramme machine referred to above. They show that at first the "effective magnetism" increases in proportion to the increase of current, then it deviates more and more until it very gradually reaches a maximum, and for still more powerful currents it decreases again. The latter peculiarity is to be accounted for by the fact, that the iron bars of the electro magnet cannot be magnetized beyond a certain point, whereas the diminishing influence of the currents on the magnetism in the iron of the armature increases continually with the strength of these currents. In practical applications such powerful currents are seldom met with, and it will suffice for the present purpose to assume, that the "effective magnetism" gradually approaches a maximum.

When two machines, identical in their construction, are connected to transmit power, the "effective magnetism" in both should be equal, as the same current circulates through both of them. The following equations will, therefore, exist between the various quantities:

$$E_1 = n M v_1 ; \quad E_2 = n M v_2 ;$$

$$C = \frac{E_1 - E_2}{R} = n M \times \frac{v_1 - v_2}{R} ;$$

$$W_1 = a \times E_1 \times C = a C^2 R \frac{v_1}{v_1 - v_2} ;$$

$$W_2 = a \times E_2 \times C = a C^2 R \frac{v_2}{v_1 - v_2} ;$$

$$H = a \times C^2 \times R ; \quad W_1 = H + W_2 ;$$

$$N = \frac{W_2}{W_1} = \frac{v_2}{v_1} = \frac{E_2}{E_1}$$

In these formulæ the index 1 refers to the machine producing the current, and the index 2 to the machine giving out the power; E stands for electro-motive force; n, M, v, P, C, signify the same quantities as before; a is a constant depending upon the construction of the machine; H is the heat, generated in the system; W_1 is the work expended upon the primary machine; W_2 is the work given out by the secondary machine; N is the useful effect.

In comparing these formulæ with observations, it is easily seen that they can not be quite correct. This is most conspicuous with the formula for the useful effect, $N = \frac{v_2}{v_1}$, according to which this should be greatest the more the velocity of the second machine approaches the velocity of the first machine, whereas actual experiments show that N is a maximum for a certain velocity of the second machine, and will decrease for any greater or lesser number of revolutions of the secondary machine. The cause of this discrepancy is the influence of the so-called Foucault currents, which are set up in the iron of the revolving armatures by the proximity of the powerful electro magnets.

In the primary machine these currents circulate in the same direction as the currents in the covering wire of the armature, and by weakening the "effective magnetism," and, consequently, the E_1 M.F $- E_1$, they increase the work W_1 expended upon the primary machine. In the secondary machine, however, in which the armature turns in the opposite direction, these Foucault currents circulate in the opposite direction to the currents of the armature wires, and by thus strengthening the effective magnetism and the electro-motive force E_2, they diminish the work W_2, given out by the secondary machine.

As our machines are supposed to be of identical construction, the following formula will express the relative propor-

tion of the different quantities relating to the Foucault currents:

$$M_1 = M - ec_1\,;\quad M_2 = M + ec_2\,;$$

$$c_1 = \frac{M_1 v_1}{u} = \frac{1}{n}\cdot\frac{E_1}{u_1}; c_2 = \frac{M_2 v_2}{u} = \frac{1}{n}\cdot\frac{E_2}{u}\,;$$

M signifies the effective magnetism, such as it would be, if no Foucault currents existed; M_1 and M_2, the actual effective magnetism of the two machines; c_1 and c_2, the strength of the Foucault currents; u, the resistance through which these currents circulate; v and n, having the same meaning as before; and e being the constant, depending on the construction of the machines.

If we calculate from the above equations the value of M_1 and M_2, substituting at the same time $y = \frac{e}{u}$; we have

$$M_1 = M(1 - yv_1)\,;\quad M_2 = M(1 + yv_2)\,;$$

and for the electro-motive force of the two machines,

$$E_1 = nM_1v_1 = nM(1 - yv_1)v_1\,;$$
$$E_2 = nM_2v_2 = nM(1 + yv_2)v_2\,;$$

this gives us for the current,

$$C = \frac{E_1 - E_2}{R} = \frac{nM}{R}[v_1 - v_2 - y(v_1^2 + v_2^2)]\,;$$

and for the work expended and given out respectively,

$$W_1 = anCM_1v_1 + ac_1M_1v_1\,;$$
$$W_2 = anCM_2v_2 - ac_2M_2v_2\,;$$

or if we substitute $p = \frac{a}{n^2u}$:

$$W_1 = aCE_1 + pE_1^2\,;\quad W_2 = aCE_2 - pE_2^2\,;$$

$$N = \frac{W_2}{W_1} = \frac{E_2}{E_1}\left\{1 - \frac{p}{aC}(E_1 + E_2)\right\};$$

$$H = aC(E_1 - E_2);\quad F_1 = pE_1^2;\quad F_2 = pE_2^2;$$
$$W_1 = W_2 + H + F_1 + F_2.$$

In these formulæ the symbols have the same signification as before, and F_1 and F_2 signify the work done by the Foucault currents.

The electrical quantities E_1, E_2, and C admit of an easy measurement, and by the help of the above formulæ, the quantities W_1 and W_2 can be determined beforehand, when the constants of the machines are known.

A great number of experiments were then made, in which all the quantities were measured, and the observed results were compared with the quantities calculated from the above formulæ, and it was found that they agreed very well. It is hardly necessary to observe that these formulæ are applicable to all types of dynamo-electric machines, whatever their construction may be, the character of each type determining the constants.

The idea of utilizing these machines for transmission of power presented itself to Dr. Werner Siemens as long ago as 1867, when he discussed at the Paris Exhibition with other members of the jury the possibility of elevated electric railroads; but the dynamo machine was at that time not sufficiently developed to admit of a practical execution of the idea, and when the present more perfect forms were invented electric lighting monopolized for a time all the attention that was bestowed upon the practical application of the machines.

During the efforts which have been made to introduce electric lighting on a large scale, the idea of applying the light-giving machines during day-time to distribute power, has come to the front again, and as such an application means a further utilization of the invested capital, the combination of lighting with transmission of power is sure to be made.

For this purpose a central station has to be established in a district, in which powerful steam engines, working on the most economical principles, drive a number of dynamo machines, which produce the electric currents. Secondary batteries, similar to those constructed by M. Planté, and improved by M. Faure, may be employed to receive the electricity, and keep it ready for use in the same manner as the gas is stored in large gas holders, and as accumulators are used in connection with hydraulic machinery.

From the station cast-iron pipes are laid through the streets, similar to those now in use for distributing gas or water, and insulated wires are drawn into them for conveying the currents from the machines to their destination. At convenient intervals the wires are made accessible by so-called "road boxes," inserted in the pipes, from which the connection to houses or lamp posts can be made. Two separate sets of wires would be required for the lighting and for the transmission of power, the com-

mutators, for directing the currents, being placed in the station; and additional commutators could be fixed in the houses for switching the current from secondary machines to lamps, without communicating with the station.

There is no doubt that much has to be learnt before all the details of such a central station, and of a practical system of distribution have been brought to perfection; but there are, now-a-days, few obstacles that cannot be surmounted, and even our present knowledge is advanced enough to teach us that there is nothing impossible in the idea sketched out above.

When a certain amount of power has to be transmitted by electricity to the given distance, it is easy to determine, experimentally, what power is required to drive the primary machine, as the exact conditions, under which the trial was conducted, can be readily reproduced in the practical application. In this respect, the transmission of power by electricity possesses a great advantage over the transmission of power by water or air, as the friction and leakage of the pipes, through which the latter have to be conducted, can never be determined in advance. It further has the advantages that the secondary machine works without producing any waste, which has to be disposed of, and that the small size and low weight of the machines obviates the necessity of heavy foundations for them.

In considering the possibility of employing the electric current to distribute power from a central station, the proportion of the power given out by the secondary machine to the power expended upon the primary machine, will not be of that deciding influence, as is generally supposed. Granted even that not more than 45 per cent. of the power expended can be reclaimed, it will still be possible to produce the power required at a cheaper rate, than if each small place had its own steam engine. For, at the central station, 1 h.p. could be produced by the large steam engines with about $2\frac{1}{4}$ lbs. of coal, so that 1 h.p. given out by the secondary dynamo machine would be produced by burning 5 lbs. of coal per hour. There are few small steam engines which will produce a horse power with that expenditure of fuel, and if we take into account the trouble and risk connected with the running of steam engines, it may be readily admitted that this loss is no real obstacle to the introduction of the electrical transmission of power. Of still less consequence will this loss be where waterfalls or other natural forces can be employed to drive the primary machines, in which case the power would cost practically nothing, beyond the interest on the capital and the depreciation of the machines. The applications which it has hitherto found have, to a certain extent, been of a tentative nature only, and on a small scale, but they are nevertheless very instructive, as they show that economical results can be obtained by it.

About three years ago, Sir William Armstrong erected a turbine at his country seat, Craigside, near Newcastle, and drives by it a Siemens dynamo-electric machine, the current of which is conducted to his residence about half a mile distant from the waterfall. In day-time this current transmits the power of the turbine to the house, where it is used for various purposes, and at night it is converted into light by means of "Swan" lamps, of which it works between thirty and forty. This application deserves special mention, because it is one of the earliest examples of transmission of power by electricity for practical and permanent purposes.

In the same way Dr. Siemens utilizes some dynamo machines at his country house near Tunbridge-wells, the power to drive the primary machines being, in this case, obtained by means of a Tangye "Soho" steam engine. The waste steam from the engine is utilized to warm the hot houses, and the gardener attending the houses takes also care of the steam engine and the dynamo machines driven by it. In this way the cost of fuel and of attendance is reduced to a minimum.

The electric current is utilized during the whole of the night to produce two lights, by the influence of which various fruits and plants are growing; and the current, in daytime, from one machine sets in motion a similar machine, which works the chaff cutter, and some other machinery, at the farm about a quarter of a mile away from the hot houses. The current from the other machine is conducted to the pumping house, a distance

of about half a mile, and the secondary machine there has supplanted a small vertical steam engine that used to pump the water up to the house. In this case, the return conductor is formed by the wire fence, care being taken to connect the wires from one side to the other of the intervening gates.

By these arrangements, one man at the farm can do the work of three; and, instead of a man having to drive a steam engine at the pumping station, to say nothing of transporting coals there, and losing time in getting up steam, he can set the pump in motion without going near the place, an occasional visit only being required for refilling the lubricators.

There are many similar instances, in which it is advantageous to connect a number of small machines, which work at irregular intervals, by means of the electrical transmission of power with one steam engine, not only when the distance between the machines is considerable, but also when they are comparatively close together.

Several applications of the latter nature have been made at Messrs. Siemens' works at Charlton; among others the apparatus for testing the mechanical strength of cables, is set in motion by a dynamo machine; and a small pump, which keeps the water in circulation in the core tanks, is driven by another machine. In both cases it would have been more costly to transmit the necessary power in the usual way by shafts and belting. A few months ago a machine was placed upon a crane on the wharf, and it was found that by it a ton could be lifted about 12 feet per minute, and smaller weights proportionally quicker. It is only fair to add, that the crane was not constructed for the purpose, and that the arrangement was made more with the view to demonstrate the possibility of working cranes by electricity, than to obtain the best results.

The electrical transmission of power, on account of the compactness of the machines, and the ease with which the conducting cables can be shifted, is particularly adapted to be used in cases where the driven machinery is erected only for temporary purposes. As an example, it may be mentioned that, when the cable ship "Faraday" was last at the works of Messrs. Siemens, the machinery, by which the cable is pulled on board, was driven part of the time by a dynamo-electric machine.

Another illustration of the same kind was furnished by M. Felix, of Sermaize-les-Bains (Marne), who worked, in June, 1879, one of Howard's double-furrow plows by a Gramme dynamo machine. The motion was conveyed from the electrical machine to a drum, and thence by a coil of wire to the plow. There was no stoppage of any kind, but the plow did its work steadily, digging up the ground to the depth of about eight inches. In the following year, M. Felix showed at the local agricultural exhibition at Bar-le-duc a plow and a threshing machine, both worked by electrical transmission of power, with perfect success.

As mentioned above, one of the first thoughts of Dr. Werner Siemens was to employ dynamo-electric machines for working elevated railroads, but it was only about three years ago that he was induced to take the matter into serious consideration, by the owner of a coal mine asking him to design a locomotive to draw the coal wagons in the mine. The result was that Messrs. Siemens and Halske showed at the Berlin Exhibition, in the summer of 1879, the model of an electric railway, which has since been exhibited at Dusseldorf and Brussels, and is at present working in the Crystal Palace. The total length of this circular railway was at Berlin 300 meters, and the gauge one meter. A dynamo machine, mounted on a carriage by itself, served as locomotive, and the passengers were conveyed in three carriages, each having seats for six persons. The current was conveyed from the primary machine to a rail laid between the rails on which the carriages run; thence it was taken off by brushes fixed to the machine and sliding on the center rail, it returned to the primary machine by the outer rails. When the carriages were prevented from moving, the locomotive exerted a pull of about 4 cwt. (200 kilos.) on them; and when the train was in regular motion, the pull varied between $1\frac{1}{2}$ cwt. and $1\frac{3}{4}$ cwt. (70-80 kgr.) which represents, as the speed was about 10 feet (3 meters) per second, three-horse power.

Small as the railway was, it clearly

demonstrated that such a mode of transport is feasible; and the advantages of having light carriages, of being able to propel them without noise and smoke, induced Messrs. Siemens and Halske to lay before the authorities in Berlin a plan to make an elevated railway through one of the streets in Berlin, altogether about 6¼ miles (10 kilom.) long.

Along the curbstones of the streets, iron columns, formed by two-channel irons, were to be erected, about 11 yards apart, carrying wooden sleepers on top, which, in their turn, support longitudinal girders. To ensure the stability of the structure, wooden struts keep the girders apart, and serve, at the same time, to insulate them from each other. The clear height, from the level, of the street to the under side of the girder is about 14 ft. 6 in. (4.4 meter), and the depth of the girder about 16 in. (40 cm.) Steel rails are laid on top of the girders, and the girder and rail on one side serve as the conductor from the primary machine, and the other rail and girder form the return wire; in this way the electrical resistance of the line is reduced to a very low figure.

The gauge of the line was to be one meter, and the carriages, resembling ordinary tram cars, were to be about 5′.5″ broad (1.65 m.) and 8 feet (2.46 m.) high above the rails. The dynamo machine, placed out of sight, underneath the car, imparts the motion by means of belts to the two wheels, which have to be insulated from each other, as the current arrives through one rail, passes through the machine, and returns by the other rail as described above.

The speed these carriages were intended to travel is 30 kilometers (18.6 English miles) per hour, and ten of them were to be supplied for the railway, of which six would be in use, and four in reserve, 10 h. p. being required to drive the primary machine of each carriage, The cost was carefully worked out, and, as it serves as an indication what such railways may be expected to cost, a short summary of the principal items will not be out of place:

FIRST COST OF 10 KILOMETERS (6¼ MILES), ELEVATED RAILWAY, SINGLE LINE.

Railway itself, including 10 stations	£61.000
Ten carriages, to hold 15 persons each	3,150
Stationary steam engine and dynamo-machine	1,950
Buildings	1,185
Land	4,500
General expenses	715
	£72,500

or about £11,600 per mile.

This estimate includes the cost of erection of the railway, and of the station, at which the steam engine works, together with the necessary buildings to protect the rolling stock against the weather, when it is not used. The cost of working the railway was calculated to be, for one year:

CURRENT EXPENSES.

Wages	£2,190
Fuel	1,110
Oil and waste	50
Lighting	80
	£3,420

DEPRECIATION AND REPAIRS.

3% on £72,500 (railway and buildings)	£1,875
16% on £5,000 (carriages and machinery)	800
	£2,675

INTEREST ON CAPITAL.

5% on £75,500	£3,625
Total cost per annum	£9,720

or about £4 6*s.* per English mile per day.

The intention was to run about 200 trains per day, and if the charge of 1*d.* per mile had been made, the £4 6*s.* per mile could have been earned, if on the average five or six persons had been conveyed in each case. The concession for this railroad was not granted, partly because the inhabitants strongly objected to having people looking into their first floor windows, and partly because the Emperor did not wish to see "The Linden," which this electric railway was to cross, disfigured.

Subsequently, Messrs. Siemens and Halske obtained permission to build a railway on the ground level from Lichterfelde, a suburban station on the Berlin-Anhalt Railway to the Military Academy, and this railway has just been successfully opened for regular traffic. It is a single line of 1 meter gauge, a little over 1½ English miles long. The permanent way has been constructed in exactly the same way as that of railways; wooden sleepers and steel rails are employed, the rails being connected, in addition to the

usual fish plates, by short straps of iron, bent in the shape of a bridge, so as to admit the adjustment of the rails to different temperatures, and to reduce at the same time the electrical resistance. As the currents are low-tension currents, it was not necessary to provide further insulation, and no difficulty is experienced in using one rail as the positive, and the other as the negative conductor.

About a third of a mile from the Lichterfelde station the primary machine, with its steam engine, is erected in the engine house of the water works, and the current is conveyed from there to the rails by underground cables. The car is exactly similar to an ordinary tram car, and is constructed to hold 20 persons besides the guard. It is symmetrical, and can move backward and forward, each end being provided with a starting lever for the guard, a brake handle and a signal bell. The dynamo machine is placed underneath the car, and transmits its movement to the wheels by means of spiral steel springs. The tires of the wheels are insulated from their axles, and are in electrical connection with brass rings, fastened on the axles, but insulated from them. Contact brushes press against these brass rings, and from them the current is conducted to the dynamo machine, and sets it in motion.

The authorities were, for some time, doubtful how to class this novel railway, and after long deliberation they have decided to rank it as a one-horse tram car. In consequence of this decision, the average speed on the railway must not exceed 9.3 English miles (15 kilometers) per hour, and the greatest speed at any moment must not exceed 12.4 English miles (20 kilometers) per hour. The time for traversing the whole distance is, therefore, not to be less than ten minutes, although the car could make the journey in about half the time with perfect safety.

If the railway continues to work in a satisfactory manner it is to be extended, and there is no doubt that the success of the railway at Lichterfelde will greatly assist in the further introduction of electrical railways, either on the level of the streets, or elevated, like the steam railways of New York. Over any other system, worked by steam or by compressed air, the electrical has the advantage that no heavy machinery has to be carried about to set the train in motion. The carriages can, therefore, be built in a lighter manner, thus reducing the power necessary to move them, and permitting all bridges and other superstructures to be built more cheaply than usual. Several carriages, each with a dynamo machine, can be joined to one train, and by this distribution of the motive power much steeper inclines can be overcome than when the same train is drawn by a single locomotive.

In addition to the ordinary brakes, means can be provided to short circuit the machines on the carriages, and to cause them in this way to act as very powerful brakes. The use of large stationary engines reduces the amount of fuel necessary to develop a certain power on the traveling carriage, and if waterfalls can be utilized, the cost of working these railways will be further diminished. It seems, therefore, probable that such railways can be usefully and economically constructed to facilitate the traffic in crowded streets, or in situations where local circumstances favor their application.

From all that has been done during the last few years, it is quite evident that the art of transmitting power by electricity has advanced rapidly, and that its practical application is continually gaining ground. This, however, should not be regarded as a sign that the electric transmission will supersede every other system of transmitting power to a distance, but rather that there is a sphere for it, where it meets existing demands better than our present means; and it should, therefore, not be treated as an enemy of existing systems, but as a supplement to them, by the aid of which problems can be solved, that could not otherwise be attempted.

DISCUSSION.

The CHAIRMAN said the subject brought before them that evening was one which, though of the highest importance, had been presented in a modest, unassuming manner; but there was in the paper matter for very deep consideration. The great utility of some means of transmitting power to a distance had long been recognized, and must be appreciated by all who thought on the subject. The

same argument was frequently made use of which had been advanced to-night, that if power could be laid on to houses in small quantities, it might turn the course of industry from the system of large factories to a system in which each workman might work in his own dwelling; but he was not at all prepared to say that such a change, except in special cases, was desirable. The probability was that the workman would have bad ventilation, that he would not attend to his duties so well as he would in a large factory, and that all the economies arising from a well-organized establishment and the sub-division of processes would be done away with, the only advantage being the somewhat sentimental one, that the man worked in his own house. However, this was rather a question for the political economist than for an engineer. Attempts at transmitting power from a distance had been made for many years. He was apprenticed to an engineer (John Hague) who was the very earliest to make the attempt on a large scale. His mode was the exhaustion of air by pumps worked by water wheels or other suitable prime movers, the exhausted mains being connected to engines in the nature of a steam engine, and the pressure which the atmosphere exerted on the piston caused it to work. In that way power was conveyed very well indeed—considering the time at which it was done—and very usefully. Notably, it was conveyed to underground engines in coal mines, where it provided a motor free from the objections of steam engines in such positions; it was also conveyed from a steam engine into gunpowder manufactories, so as to obviate the necessity of fires within the manufactory. Since then they had had the transmission of power by compressed air, and also by water under pressure, as perfected by Sir William Armstrong, by means of accumulators and various hydraulic engines. He could not quite agree with Mr. Alexander Siemens, that the great advantage in the electric mode of transmission over these last two, lay in the fact that with them the loss by friction and leakage could not be accurately calculated; because the loss by friction was easily calculated, and that by leakage was dependent on the care with which the work was carried out, and it ought to be, and was in fact, extremely small. Then again, there was the transmission of power by means of endless ropes, of which there was a magnificent example at Shaffhausen, where the water of the Rhine was made to work large turbines which drove endless ropes; these were carried about three-quarters of a mile along the bank of the river, and drove shafting under the side streets, from which the power was laid on to various houses, and he did not know a more interesting sight than to see the power of the Rhine thus utilized. But this evening we had before us a means of transmitting power by electricity, and no doubt if such a slender conductor as was on the table could be substituted for the large exhausted main of John Hague, for the smaller main carrying compressed air, or the still smaller one carrying water under pressure, or for the rope running over guide pulleys; a great step would be gained. Mr. Alexander Siemens had put it that this mode would be economical even supposing only 45 per cent. of the power developed in the steam engine was available at the spot where it was utilized, and did so, on account of the greater economy in working one large central steam engine, rather than a number of small ones, and in that he quite agreed with him, as also in the statement that 2¼ lbs. of coal per h. p. was a liberal allowance for a large condensing engine, and that at least 5 lbs. were used in small non-condensing engines. He had also pointed out that where water power was available, it might be utilized in a manner which it could not be at present, as, instead of factories having to be built in inaccessible, out-of-the-way places, the dynamo machines could be placed there, and connected by wires to sites where the manufactures could be carried on with comfort, and where transport was easy. He had the good fortune to see the arrangements of Sir William Armstrong, at Craigside; there was a fall of water which drove the machine, the wires were led to the house nearly three-quarters of a mile off, and during the day the force was employed to work a saw bench, and at night for illuminating the house. He had not been there since the Swan lights were introduced; but Sir William Armstrong wrote to him a couple of months ago, saying that the lighting had

been much improved since he saw it Sir, William stated that the light was perfect so much resembling day light that, at the time of writing, he had even been obliged to get up and draw the curtains, because there was a thrush outside trying to commit suicide by coming through the window. It appeared that the authorities at Berlin did not know how to classify this new railway; but their putting it down as a one-horse tram car reminded him of a curious classification he heard of not long ago, when he visited the celebrated cavern near Trieste. This was lit by candles, and the landlord of the hotel complained that the electric light had been proposed, but the Prefect objected, citing a resolution which had been passed by the authorities, that neither aluminum, electricity, nor any other smoke-producing means of illumination should be employed. With regard to another mode of using electric force, which had been touched upon in the paper, he might say that he had had all the evening a most agreeable perfume coming from a melon on the table before him, which Dr. Siemens had grown by the sun, aided by electricity; and he had no doubt it would prove as good as other fruits he had tasted from the same source. In this paper they had the opening out of a subject, the importance of which it was difficult to exaggerate. If, by means of electricity, they could practically convey power to a distance, and give it forth when required in anything like a reasonable proportion of the power originally employed, it was perfectly certain that they had thereby a means of utilizing the forces of nature, which now were wasted. All round England they had a sea which ebbed and flowed with varying range, but probably the average would be about 15 feet; and if they could, by means of water mills, utilize that enormous tidal force, and transmit it electrically to centers of population, they must economize the coal now employed for the purpose of motive power, and reserve it for those purposes for which, up to the present time, it would seem that coal was needed, viz.: for metallurgical and other similar purposes. At the same time he by no means despaired of hearing that it was no longer needed directly even for these operations, for it was beginning to appear that electricity was able to do that, in the way of melting refractory materials, which had hitherto been done by the expenditure of fuel. The subject of the paper was so large and important, that he thought it would not be too much to ask the Council of the Society to devote next Wednesday evening to a continuance of the discussion.

Professor Ayrton said the first point which occurred to him on hearing the paper, was in connection with the formula by which Mr. Siemens arrived at the result that the efficiency of electrical transmission ought to reach the maximum when the velocity of the motor was equal to that of the generator; but who went on to say that there seemed to be something wrong in this theoretical conclusion, because it was not borne out by experiment, and the explanation given was the Foucault currents which were set up by induction in the iron. He ventured to think there was another explanation altogether which would account for the formula not according with experimental results, and, indeed, he should not have predicted that the formula would agree with the results. He presumed that the experiments to which they referred were made with dynamo machines, in which the current generated by the machine was used to excite the field magnets. Now, supposing they had two dynamo-electric machines, one drvien by a steam engine, and producing a current, and the other producing work by means of that current, and imagine them running at exactly the same speed, what would be the result? There would be no currrent whatever passing the wire joining them; because, if running at the same speed, the electro-motive force of the generator must be equal and opposite to that of the motor. But if there was even little current passing between the two machines, it was impossible for the second machine to receive power at all, since there could be no magnetization of the field magnets. And yet for the motor to revolve rapidly work must be spent in friction, even if no useful work were given out; hence, it was really the use of dynamo machines which caused the theoretical result to differ from the practical. The machines which ought to be used were either dy-

namo-electric machines with separate exciters, or else magneto-electric machines. For the transmission of power efficiently and economically it was absolutely necessary that magnetization of the field magnets should not be produced by the current passing through the wires joining the two machines. But when such an arrangement as he referred to was carried out, there would be little difference between the theoretical and practical result. It would be found that the economy of the transmission increased as the velocity of the motor more and more approached that of the generator; and when both velocities were extremely high, and nearly equal, the efficiency would approach very nearly to 1. There were various considerations which would bear this out. If you made experiments, as his students had done, with magneto-electric machines as motors, measuring the electric energy put into the magneto-electric machine, and at the same time measuring the amount of work given out by it, you did not find that there was a maximum point after which the efficiency diminished. All the experiments he had seen showed that the efficiency increased with the speed; and he had actually obtained with a very high speed an efficiency of 92 per cent. He thought, on the whole, the conclusions Mr. Siemens had arrived at tended to show what Professor Perry and himself had advanced several times, that they ought to use either magneto-electric machines or dynamo machines, with separate exciters; and, to a certain extent, this conclusion was borne out by practical experience, because he learned that in electric lighting, which was but one mode of transmitting power, it was becoming the practice to use separate exciters for the dynamo machines; and that was the method adopted by Dr. Siemens in the city. As the chairman had pointed out, the great advantage of electricity as a means of transmitting power was not that the friction and leakage inseparable from other methods could not be calculated; but experiments seemed to show that electricity had no mass; that there was no inertia in it; and there was no waste of power in making it go round a corner, as there was with water or any kind of material fluid. In many respects, of course, the flow of electrictity through a wire was like the flow of water through a pipe; the quantity of current was constant, and the electricity lost potential, just as water lost head; but there was this great difference between the two, when you had to make water go round a bend you lost a great deal of power, and the form of the bend made a considerable difference. If you had two or more bends in a pipe, in opposite directions, you lost more power than if there were a continuous curve in the same direction; but this was not so with an electric conductor, since bends made absolutely no difference in the electric resistance of a wire. The chairman had alluded to the great advantage which would result from an enormous quantity of waste power being utilized, and with that he concurred, not so much with regard to the tide, the utilization of which he feared lay in the dim future, in consequence of the great expense of storing the water when the tide rose, but rather with regard to the water power of streams. It was quite lamentable to walk about the neighborhood of Sheffield and see the number of old grindstones which formerly were worked by water power, now lying idle, the grinders having all gone into Sheffield, where they used grindstones worked by steam power, which cost them more; but they saved, on the whole, on account of the expense of transportation. If those streams could be used to work magneto-electric machines, from which the power could be conveyed into the town, and there utilized, it would be an immense advantage. There was another point about electric railways which might not have struck some of those present. At present locomotives weighed from 40 to 60 tons, necessitating very substantial and expensive bridges and permanent way, and it was impossible to make them much lighter, or they would not have sufficient adhesion on the rails to pull a train; you could not much diminish the weight so long as you drove a train by one or two pair of driving wheels. But if you drove the train by nearly all the pairs of wheels, as could easily be done electrically, it might be made comparatively light, and there would be no loss by slip. The great value of the paper lay in its technical character; it was a

laudable example of the application of principles of science to practice, which characterized all the work of the Messrs. Siemens; and if he had ventured to differ a little from some small part of the theoretical considerations advanced, he would conclude by assuring the meeting that no one more highly appreciated its practical bearing.

Mr. J. N. Shoolbred said he had made some experiments on the transmission of power, and was much struck by the remarks of Professor Ayrton on the amount of useful power the formulæ disclosed, and also as to the nature of the machines which, in his opinion, would have to be employed. He agreed with him as to the errors, which had probably arisen from the use of two dynamo machines, one as the generator and the other as the motor. He had himself long seen reason to doubt the ordinary statement that there must be a loss of 50 per cent. in the second machine, and he hoped, by some means or other, they would be able to discover the proper formula. With regard to the two classes of machines, spoken of by Professor Ayrton as the best form of primary machines, either magneto machines or dynamo machines with separate exciters, he thought—especially where the same machines were used for lighting and for transmitting power in the daytime—that dynamo machines would be chiefly employed; but they would generally fall under the condition of having one common exciter, and, consequently, according to Professor Ayrton, about 80 per cent. of the original duty given off might be recovered.

Professor Ayrton wished to explain that the figures he had used, which were quoted in the paper, did not mean that if you gave a certain amount of power to the dynamo-electric machine you could get out 90 per cent. of that in the electric light produced by that machine; it only meant that 90 per cent. of the power given to the machine was reproduced as electric energy. Some of that energy was employed in producing light, but a large portion—often nearly half, or more—was employed in heating the wires or the magnets.

Dr. C. W. Siemens, F. R. S., said he would only make a few remarks that evening, and speak more at length when the discussion was resumed next week. Professor Ayrton had remarked that the dynamo machine would be superseded by the magneto machine, or by a dynamo machine with a separate exciter, and he confessed that he went a long way with him in his argument; indeed, last year he communicated a paper to the Royal Society in which he showed certain defects in the dynamo machine, and suggested certain remedies. The dynamo labored under this defect, that, with an increase of work, the power to overcome the resistance diminished. The current produced by the rotation of the coils in the magnetic field had to excite the coils of the magnet itself, and the current then passed on to the second machine or to the light, to the place where the work was to be performed. Now, if that work should present increased resistance, the machine which had to overcome it should increase in energy, whereas the greater resistance caused a weakening of the current and a falling off in the power of the magnets by which the current was produced, thus causing those fluctuations which were so troublesome in electric lamps, but which, by different arrangements, had been almost overcome, and would be entirely overcome by the aid of further experience. It was quite true that in the city they were working with dynamo machines having separate exciters, but the dynamo machine could be so arranged that a portion only of the current was set aside to excite its own magnet, and if that arrangement were properly applied, he believed all the advantages of a separate exciter could be secured with a single machine. The subject especially before them, however, was the application of electricity to the propulsion of railways and the transmission of power, of which the propulsion of carriages was only one branch. Several other methods by which propulsion could be effected might be mentioned. Only a few days ago he had been in Paris, and had arranged for the construction of a short line of comparatively broad guage, which was to be carried out by the omnibus company of Paris, in connection with the Electrical Exhibition. An ordinary tram car would be run from the Place de la Concorde to the Exhibition, upon rails laid in the usual manner, hav-

ing a suspended conductor along the side of the railway. This conductor would have a little carriage passing along it, in order to transmit the electric current from the suspended wire to the machine, and back through the rails themselves. That arrangement, which was devised by Dr. Werner Siemens, made them independent of partial insulation of the rails upon which the carriage ran, and also independent of the partial insulation of the wheels of one side from the other, leaving the rolling stock very much the same as at present, transferring the current to a separate conductor, something analogous to a single wire telegraph, upon which the contact roller ran and conveyed the current to the machine. Another arrangement by which an ordinary omnibus might be run upon the street would be to have a suspender thrown at intervals from one side of the street to the other, and two wires hanging from these suspenders; allowing contact rollers to run on these two wires, the current could be conveyed to the tram car, and back again to the dynamo machine at the station, without the necessity of running upon rails at all. He merely mentioned this to show that the system was not one which must be carried out in one particular way only, but was capable of very wide modification and extension according to circumstances.

The paper referred to certain applications which he had made of electricity, near Tunbridge Wells, to horticulture, and on the table was a melon which had been produced by the aid of the electric light.

CONTINUOUS GIRDERS.

By F. E. KIDDER, B.C.E.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

HAVING occasion to look into the subject of continuous girders, as applied to building construction, the writer was surprised to find how little has been published on the subject, and how scattered and inconvenient that little is. Thinking, therefore, that a table of formulæ for the more common cases of continuous girders would be very useful and convenient, the writer has prepared the following paper giving the various formulæ, with their derivation, for continuous girders of two and three spans loaded in such ways as often occur in practice. Such of the formulæ as correspond to those given by other writers have been very carefully verified by comparison, and many which could be verified in no other way have been tested by experiments made for the purpose.

The general formulæ for continuous girders of uniform cross section are taken from "Rankine's Civil Engineering," pages 287 and 288.

In these and the subsequent formulæ, the following notation will be adopted:

Let E denote the modulus of elasticity of the material.

F_1	"	" shearing force just to right of origin.
F_{-1}	"	" shearing force just to left of origin.
I	"	" moment of inertia of the cross section.
l	"	" length of span to right of origin.
l_1	"	" length of span to left of origin.
M	"	" bending moment at any given section.
M_0	"	" bending moment at the origin.
M_1	"	" bending moment over support to right of origin.
M_{-1}	"	" bending moment over support to left of origin.
T_1	"	" slope at $x=o$, in span to right of origin.
T_{-1}	"	" slope at $x=o$, in span to left of origin.

v denote the deflection at any given point.
w " " " distributed load per unit of span l.
w_1 " " " distributed load per unit of span l_1.
x " " horizontal distance of any given section from the origin.

Let all horizontal distances to the right of origin be positive, and those to the left negative.

Let v and the vertical forces be *positive downwards.*

General formulæ.—The general formulæ for continuous girders, with uniformly distributed loads, given by Rankine are:

$$M = M_o - F_x + m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$v = T_x - F_q + M_o n + V \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$F_1 = \frac{M_o - M_1 + m_1}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$T = M_o\left(\frac{q_1}{l^2} - \frac{n_1}{l}\right) - \frac{M_1 q_1}{l^2} + \frac{m_1 q_1}{l^2} - \frac{V_1}{l} \quad . \quad (4)$$

$$T_{-1} = M_o\left(\frac{q_{-1}}{l_1^2} - \frac{n_{-1}}{l_1}\right) - \frac{M_{-1}\, q_{-1}}{l_1^2} + \frac{m_{-1}\, q_{-1}}{l_1^2} - \frac{V_{-1}}{l_1} \quad . \quad . \quad . \quad (5)$$

Expression for the theorem of the three moments

$$0 = M_o\left(\frac{q_1}{l^2} + \frac{q_{-1}}{l_1^2} - \frac{n_1}{l} - \frac{n_{-1}}{l_1}\right) - \frac{M_1 q_1}{l^2} - \frac{M_{-1}\, q_{-1}}{l_1^2} + \frac{m_1 q_1}{l^2} + \frac{m_{-1}\, q_{-1}}{l_1^2} - \frac{V_1}{l} - \frac{V_{-1}}{l_1} - t. \quad . \quad (6)$$

In which the letters m, n, q and V, represent the following quantities:

$$m_1 = \int_0^l \int_0^x w\,dx^2 \qquad m_{-1} = \int_0^{l_1} \int_0^x w_1\,dx^2$$

$$n_1 = \int_0^l \int_0^x \frac{dx^2}{EI} \qquad n_{-1} = \int_0^{l_1} \int_0^x \frac{dx^2}{EI}$$

$$q_1 = \int_0^l \int_0^x \frac{x\,dx^2}{EI} \qquad q_{-1} = \int_0^{l_1} \int_0^x \frac{x\,dx^2}{EI} \quad . \quad (A)$$

$$V_1 = \int_0^l \int_0^x \frac{dx^2}{EI} \int_0^x \int_0^x w\,dx^2$$

$$V_{-1} = \int_0^{l_1} \int_0^x \frac{dx^2}{EI} \int_0^x \int_0^x w_1\,dx^2.$$

When these letters are used without the subscripts 1 and -1, as in the formulæ for V and M, they should be integrated between the limits x and o instead of l and o. The letter $t = T_1 - T_{-1}$, and denotes the tangent of the small angle made by the neutral layers of the two spans with each other. In the cases which we shall consider, $t = o$.

To extend the general formulæ to the case of concentrated loads, let W_1 represent any one of the concentrated loads applied at a distance x_1 from the origin to the right; and W_{-1} any concentrated load applied at a distance x_{-1} from the origin to the left.

Then in the formulæ 1 to 6, inclusive, we must make the following changes:

Instead of $m_1 = \int_0^l \int_0^x w\,dx^2$, put

$$m_1 = \int_0^l \int_0^x w\,dx^2 + \Sigma W_1 (l - x)$$

the summation extending as far as the load only.

Instead of

$$V_1 = \int_0^l \int_0^x \frac{dx^2}{EI} \int_0^x \int_0^x w\,dx^2, \text{ put} \quad (B)^*$$

$$V_1 = \int_0^l \int_0^x \frac{dx^2}{EI} \int_0^x \int_0^x w\,dx^2 + \Sigma W_1 \int_{x_1}^l \int_{x_1}^x \frac{(x - x_1)\,dx}{EI};$$

and make the corresponding changes in m_{-1} and V_{-1}. n and q will remain as before.

We will now apply the general formulæ just given to the following particular cases, in all of which the girder is supposed to be of uniform cross section.

*For these values the writer is indebted to Prof. Gaetano Lanza, of the Massachusetts Institute of Technology.

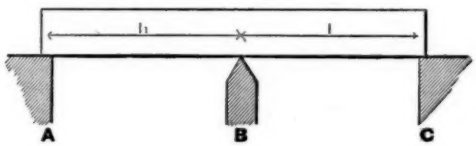
Case I.

Continuous girder of two spans, with uniformly distributed load.

Let l_1 = length of span AB.
l = " " " BC.
w = load per linear unit of BC.
w_1 = " " " " AB.
R_1, R_2, R_3 = the reactions at the supports A, B and C, respectively.

Take origin of co-ordinates at B, and denote the bending moment at that point by M_B, or $M_O = M_B$.

As there can be no bending moment at the supports A and C, $M_1 = M_{-1} = O$, also $t = o$.



$$m_1 = \int_0^l \int_0^x w dx^2 \frac{wl^2}{2}, \qquad m_{-1} = \frac{w_1 l_1^3}{2}$$

$$n_1 = \int_0^l \int_0^x \frac{dx^2}{EI} = \frac{l^3}{2EI}; \qquad n_{-1} = \frac{l_1^3}{2EI}$$

$$q_1 = \int_0^l \int_0^x \frac{x dx^2}{EI} = \frac{l^3}{6EI}; \qquad q_{-1} = \frac{l_1^3}{6EI}$$

$$V_1 = \int_0^l \int_0^x \frac{dx^2}{EI} \int_0^x \int_0^x w dx^3 = \frac{wl^4}{24EI};$$

$$V_{-1} = \frac{w_1 l_1^4}{24EI}.$$

Substituting these values in eq. 6 we have

$$O = M_B\left(\frac{l}{6EI} + \frac{l_1}{6EI} - \frac{l}{2EI} - \frac{l_1}{2EI}\right) + \frac{wl^3}{12EI} + \frac{w_1 l_1^3}{12EI} - \frac{wl^3}{24EI} - \frac{w_1 l_1^3}{24EI};$$

and by combining and eliminating we obtain the expression

$$M_B = \frac{wl^3 + w_1 l_1^3}{8(l + l_1)} \quad . \quad . \quad . \quad . \quad (7)$$

From equation 3 we obtain:

Shearing force at A (taking origin at that point) =

$$R_1 = \frac{-M_B + m_{-1}}{l_1} = \frac{w_1 l_1}{2} - \frac{wl^3 + w_1 l_1^3}{8 l_1 (l + l_1)} \quad . \quad (8)$$

Shearing force just to left of B =

$$F_{-1} = \frac{M_B + m_{-1}}{l_1} = \frac{w_1 l_1}{2} + \frac{wl^3 + w_1 l_1^3}{8 l_1 (l + l_1)}$$

Shearing force just to right of B =

$$F_1 = \frac{M_B + m_1}{l} = \frac{wl}{2} + \frac{wl^3 + w_1 l_1^3}{8l(l + l_1)}$$

$$R_2 = F_1 + F_{-1}$$

Shearing force at C =

$$R_3 = \frac{wl}{2} - \frac{wl^3 + w_1 l_1^3}{8l(l + l_1)} \quad . \quad . \quad . \quad . \quad (9)$$

Shearing force at distance x from A

$$= -R_1 + w_1 x.$$

Shearing force at distance x from C

$$= -R_3 + wx.$$

From eq. 1 we find:

Bending moment at distance x from A =

$$M = -R_1 x + \frac{w_1 x^2}{2} \quad . \quad . \quad . \quad (10)$$

Bending moment at distance x from B =

$$M = M_B - F_1 x \frac{wx^2}{2} \quad . \quad . \quad . \quad (11)$$

From eq. 4 we find:

Slope at A =

$$T_{-1} = -\frac{M_B l_1}{6EI} + \frac{w_1 l_1^3}{12EI} - \frac{w_1 l_1^3}{24EI} = -\frac{M_B l_1}{6EI} + \frac{w_1 l_1^3}{24EI} \quad . \quad . \quad . \quad . \quad (12)$$

Slope at B, in span BC =

$$T_1 = M_B\left(\frac{l}{6EI} - \frac{l}{2EI}\right) + \frac{wl^3}{12EI} - \frac{wl^3}{24EI} = -\frac{M_B l}{3EI} + \frac{wl^3}{24EI} \quad . \quad . \quad (13)$$

From eq. 2:

Deflection in span AB at distance x from A =

$$v = T_{-1} x - \frac{R_1 x^3}{6EI} + \frac{w_1 x^4}{24EI} \quad . \quad . \quad (14)$$

Deflection in span BC at distance x from B =

$$v=T_1x-\frac{F_1x^3}{6EI}+\frac{M_Bx^2}{2EI}+\frac{wx^4}{24EI} \quad . \quad . \quad . \quad (15)$$

In practice both spans are generally loaded alike, so that $w=w_1$, which somewhat simplifies the above formulæ.

EXAMPLE I.—*Given a continuous girder of two equal spans, with a distributed load of w lbs. per linear unit over each; to find the reactions of the supports, the greatest bending moment and the deflections.*—First find the bending moment M_B. This we can obtain directly from eq. 7, by making $w=w_1$, and $l=l_1$. Making these substitutions we have

$$M_B=\frac{wl^2}{8} \quad . \quad . \quad . \quad . \quad (16)$$

Making the same substitutions in equations 8 and 9, we have

$$R_1=R_2=\tfrac{3}{8}\,wl \quad . \quad . \quad . \quad . \quad (17)$$

$$R_2=\tfrac{5}{4}\,wl \quad . \quad . \quad . \quad . \quad . \quad (18)$$

Bending moment at distance x from A or C =

$$M=-R_1x+\frac{wx^2}{2}=-\tfrac{3}{8}wlx+\frac{wx^2}{2} \quad . \quad . \quad (19)$$

If we differentiate this expression and put the first coefficient equal to zero, we have

$$o=-\tfrac{3}{8}\,wl+wx; \text{ or } x=\tfrac{3}{8}\,l$$

which is the value of x for which the bending moment in either span is a maximum. Substituting this value for x, we have:

Greatest bending moment in either span =

$$M=-\frac{9}{128}wl^2 \quad . \quad . \quad . \quad . \quad (20)$$

The greatest bending moment in the girder is therefore over the middle support, and equals M_B.

Slope at A, from eq. 12, =

$$T=\frac{wl^3}{48EI}.$$

Deflection at distance x from A or C=

$$v=\frac{wl^2x}{48EI}-\frac{wlx^3}{16EI}+\frac{wx^4}{24EI}=$$

$$\frac{w}{48EI}(l^2x-3lx^3+2x^4) \quad . \quad . \quad (21)$$

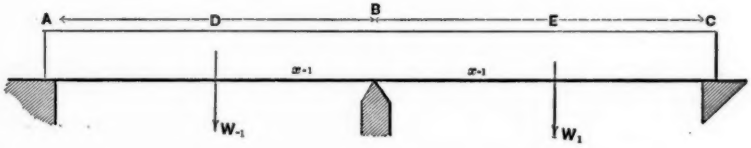
The deflection is greatest when $x=.421535\ l$; and hence the greatest deflection in either span =

$$v=.005416\frac{wl^4}{EI} \quad . \quad . \quad . \quad . \quad (22)$$

If we put eq. 19 equal to zero, we shall be able to deduce the value of x for which the bending moment is zero, or, as this point is the point of inflection, to determine the distance of that point from the end. Performing the operation, we find that when $M=o$, $x=\frac{3}{4}\,l$, hence the points of inflection are at $\frac{3}{4}$ the span from either abutment.

CASE II.

Continuous girder of two spans, with both distributed and concentrated loads:



Let l =length of span BC.
" l_1 = " " " AB.
" w_1 =the load per linear unit of AB.
" w = " " " " " " BC.
" W_1 =concentrated load on BC at distance x_1 from B.
" W_{-1} =concentrated load on AB at distance x_{-1} from B.
" R_1, R_2, R_3=the reactions at the supports A, B and C respectively.

Take origin of co-ordinates at B, then $t=o$; $M_2=M_B$; $M_1=M_{-1}=o$; and from A and B

$$m_1=\int_0^l\int_0^x w\,dx^2+W_1(l-x_1)=$$

$$\frac{wl^2}{2}+W_1(l-x_1);\quad m_{-1}=\frac{w_1l_1^2}{2}+W_{-1}(l-x_{-1}).$$

$$n_1=\int_0^l\int_0^x\frac{dx^2}{EI}=\frac{l^2}{2EI};\qquad n_{-1}=\frac{l_1^2}{2EI}.$$

$$q_1=\int_0^l\int_0^x\frac{x\,dx^2}{EI}=\frac{l^3}{6EI};\qquad q_{-1}=\frac{l_1^3}{6EI}.$$

$$V_1=\int_0^l\int_0^x\frac{dx^2}{EI}\int_0^x\int_0^x w\,dx^3+\frac{W_1}{EI}\int_{x_1}^l\int_{x_1}^x(x-x_1)dx^2=\frac{wl^4}{24}+\frac{W_1(l-x_1)^3}{6EI}.$$

$$V_{-1}=\frac{w_1l_1^4}{24EI}+\frac{W_{-1}(l_1-x_{-1})^3}{6EI}.$$

Substituting these values in eq. 6, we have

$$0=M_B\left(\frac{l}{6EI}-\frac{l}{2EI}+\frac{l_1}{6EI}-\frac{l_1}{2EI}\right)+\frac{wl^3}{12EI}+\frac{w_1l_1^3}{12EI}+\frac{W_1l(l-x_1)}{6EI}+\frac{W_{-1}l_1(l_1-x_{-1})}{6EI}-\frac{wl^3}{24EI}-\frac{w_1l_1^3}{24EI}-\frac{W_1l(l-x_1)^3}{6EI}-\frac{W_{-1}l_1(l_1-x_{-1})^3}{6EI};$$

from which we obtain

$$M_B=\frac{wl^3+w_1l_1^3}{8(l+l_1)}+\frac{W_1l(l-x_1)+W_{-1}l_1(l_1-x_{-1})}{2(l+l_1)}-\frac{W_1(l-x_1)^3}{2l(l+l_1)}-\frac{W_{-1}(l-x_{-1})}{2l_1(l+l_1)}. \quad \ldots (23)$$

From eq. 3 we find:

Shearing force at A (taking origin at A) =

$$R_1=\frac{-M_B+\frac{w_1l_1}{2}+W_{-1}(l_1-x_{-1})}{l_1}. \quad (24)$$

Shearing force just to left of B =

$$F_{-1}=\frac{M_B+\frac{w_1l_1^2}{2}+W_{-1}(l_1-x_1)}{l_1}.$$

Shearing force just to right of B =

$$F_1=\frac{M_B+\frac{wl^2}{2}+W_1(l-x_1)}{l}.$$

$$R_2=F_{-1}+F_1.$$

Shearing force at C =

$$R_3=\frac{-M_B+\frac{wl^2}{2}+W_1(l-x_1)}{l} \quad \ldots (25)$$

Shearing force in section AD at distance x from A

$$=-R_1+w_1x.$$

Shearing force in section DB at distance x from A

$$=-R_1+w_1x+W_{-1}.$$

Shearing force in section BE at distance x from B

$$=-F_1+wx.$$

Shearing force in section EC at distance x from B

$$=-F_1+wx+W_1.$$

From eq. 1, we obtain:

Bending moment in section AD at distance x from A

$$=-R_1x+\frac{w_1x^2}{2}.$$

Bending moment in section DB at distance x from A

$$=-R_1x+\frac{w_1x^2}{2}+W_{-1}[x-(l_1-x_{-1})].$$

Bending moment in section BE at distance x from B

$$=M_B-F_1x+\frac{wx^2}{2}.$$

Bending moment in section EC at distance x from B

$$=M_B-F_1x+\frac{wx^2}{2}+W_1(x-x_1).$$

From eq. 4:

Slope at A =

$$T_{-1}=-\frac{M_Bl_1}{6EI}+\frac{w_1l_1^3}{6EI}+\frac{W_{-1}l_1(l_1-x_{-1})}{6EI}-\frac{w_1l_1^3}{24EI}-\frac{W_{-1}(l_1-x_{-1})^3}{6l_1EI}.$$

Slope at B, in span BC =

$$T_1=-\tfrac{1}{3}\frac{M_Bl}{EI}+\frac{wl^3}{6EI}+\frac{W_1l(l-x_1)}{6EI}-\frac{wl^3}{24EI}-\frac{W_1(l-x_1)^3}{6lEI}.$$

From eq. 2:

Deflection in section AD at distance x from A =

$$v=T_{-1}x-\frac{R_1x^3}{6EI}+\frac{w_1x^4}{24EI}.$$

Deflection in section DB at distance x from A =

$$v=T_{-1}x-\frac{R_1x^3}{6EI}+\frac{w_1x^4}{24EI}+\frac{W_1(x-x_1)^3}{6EI}.$$

Deflection in section BE at distance x from B =

$$v=T_1x-\frac{F_1x^3}{6EI}+\frac{M_Bx^2}{2EI}+\frac{wx^4}{24EI}.$$

Deflection in section EC at distance x from B =

$$v=T_1x-\frac{F_1x^3}{6EI}+\frac{M_Bx^2}{2EI}+\frac{wx^4}{24EI}+\frac{W(x-x_1)^3}{6EI}.$$

The position of the point of greatest deflection will depend upon the proportion of the loads and spans, and must be found for each separate case.

EXAMPLE II. — *Given a continuous girder of two equal spans, loaded at the center of the right span with a load of* W_1 *lbs., and at the center of the left span with* W_{-1} *lbs; and having no distributed load; to find the reactions of the supports, the greatest bending moments, and the deflections.*—In this example, $l=l_1$, $w_1=w=o$, and $x_1=x_{-1}=\frac{l}{2}$. Making these substitutions in the formulæ of Case II we obtain:

Bending moment over center support =

$$M_B=\tfrac{3}{32}l(W_1+W_{-1}) \quad . \quad . \quad (26)$$

$$R_1=\frac{13W_{-1}-3W_1}{32} \quad . \quad . \quad . \quad . \quad (27)$$

$$R_2=\tfrac{11}{16}(W_1+W_{-1}) \quad . \quad . \quad . \quad . \quad (28)$$

$$R_3=\frac{13W_1-3W_{-1}}{32} \quad . \quad . \quad . \quad . \quad (29)$$

Bending moment in section AD at distance x from A =

$$M=\frac{(3W_1-13W_{-1})x}{32}$$

Bending moment in section DB at distance x from A =

$$M=W_{-1}\left(x-\frac{l}{2}\right)-\frac{(13W_{-1}-3W_1)x}{32}.$$

Bending moment in section EC at distance x from B =

$$M=\tfrac{3}{32}(W_1+W_{-1})l-\tfrac{3}{32}(W_1+W_{-1})x-\frac{W_1x}{2}-W_1\left(x-\frac{l}{2}\right).$$

Greatest bending moment in right span, equals bending moment at center =

$$M=\frac{(3W_{-1}-13W_1)l}{64} \quad . \quad . \quad (31)$$

Greatest bending moment in girder is therefore M_B (eq. 26).

Slope at A =

$$T_{-1}=\frac{(3W_{-1}-W_1)l^2}{64EI}.$$

Deflection at center of left span =

$$v=\frac{(23W_{-1}-9W_1)l^3}{1536EI} \quad . \quad . \quad . \quad (32)$$

Slope at B in span BC =

$$T_1=\frac{(W_1-W_{-1})l^2}{32EI}=o, \text{ when } W_1=W_{-1}.$$

Deflection at center of right span =

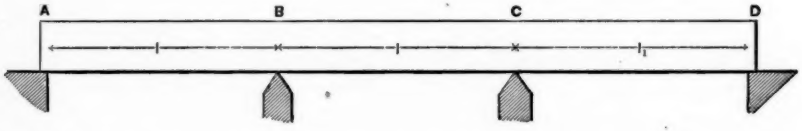
$$v=\frac{(23W_1-9W_{-1})l^3}{1536EI} \quad . \quad . \quad . \quad . \quad (33)$$

There are two special cases under this example, mentioned by Moseley, which deserve pointing out.

First, when $W_{-1}=3W_1$, the right span of the girder will be horizontal; and second, when $3W_{-1}=13W_1$ the reaction of the right abutment will be zero.

CASE III.

Continuous girder of three spans with uniformly distributed load only.



Greatest bending moment in left span equals bending moment at center =

$$M=\frac{(3W_1-13W_{-1})l}{64} \quad . \quad . \quad . \quad . \quad (30)$$

Bending moment in section BE at distance x from B =

$$M=\tfrac{3}{32}(W_1+W_{-1})l-\tfrac{3}{32}(W_1+W_{-1})x-\frac{W_1x}{2}.$$

Let l_1 = length of span AB and CD.
" l = " " " BC.
" w = the load per linear unit of BC.
" w_1 = " " " " " " AB, and CD.
" R_1, R_2, R_3, R_4 = the reactions of the supports at A, B, C and D respectively.

First take origin at B, then $t=o$; $M_o=M_B$; $M_{-1}=o$; $M_1=M$;

$$m_1=\frac{wl^2}{2}\ ;\quad m_{-1}=\frac{w_1l_1^2}{2}$$

$$n_1=\frac{l^2}{2EI};\quad n_{-1}=\frac{l_1^2}{2EI}$$

$$q_1=\frac{l^3}{6EI};\quad q_{-1}=\frac{l_1^3}{6EI}$$

$$V_1=\frac{wl^4}{24EI};\quad V_{-1}=\frac{w_1l_1^4}{24EI};$$

and

$$o=M_B\left(\frac{l}{6EI}+\frac{l_1}{6EI}-\frac{l}{2EI}-\frac{l_1}{2EI}\right)-\frac{M_Cl}{6EI}+\frac{wl^3}{12EI}+\frac{w_1l_1^3}{12EI}-\frac{wl^3}{24EI}-\frac{w_1l_1^3}{24EI},$$

or $8M_B(l+l')+4M_Cl=wl^3+w_1l_1^3$.

As the girder is symmetrically loaded and supported on either side of the center, M_C must equal M_B, hence

$$M_B=\frac{wl^3+w_1l_1^3}{4(3l+2l')} \quad . \quad . \quad . \quad . \quad (34)$$

From eq. 3 we obtain:

Shearing force at A or B (origin at A) =

$$R_1=R_4=\frac{-M_B+\frac{w_1l_1^2}{2}}{l_1}=\frac{w_1l_1}{2}-\frac{wl^3+w_1l_1^3}{4l_1(3l+2l')} \quad . \quad . \quad . \quad (35)$$

Shearing force just to left of B, or right of C =

$$F_{-1}=\frac{M_B+\frac{w_1l_1^2}{2}}{l_1}=\frac{w_1l_1}{2}+\frac{wl^3+w_1l_1^3}{4l_1(3l+2l')}.$$

Shearing force just to right of B, or left of C =

$$F_1=\frac{M_B-M_C+\frac{wl^2}{2}}{l}=\frac{wl}{2}$$

$$R_2=R_3=F_{-1}+F_1=\frac{wl+w_1l_1}{2}+\frac{wl^3+w_1l_1^3}{4l_1(3l+2l_1)} \quad . \quad . \quad . \quad . \quad (36)$$

Shearing force in span AB or CD at distance x from A or D

$$=-R_1+wx.$$

Shearing force in middle span at distance x from B or C

$$=-F_1+wx=-\frac{wl}{2}+wx.$$

From eq. 1:

Bending moment in span AB or CD at distance x from A or D =

$$M=-R_1x+\frac{wx^2}{2}.$$

Bending moment in middle span at distance x from B or C =

$$M=M_B-F_1x+\frac{wx^2}{2}.$$

The greatest bending moment in middle span is when $x=\frac{l}{2}$, or

$$M=M_B-\frac{wl^2}{8}.$$

The position of the point of greatest bending moment in the end spans depends upon the proportions of w and w_1 and l and l_1 to each other. When the spans and loads are equal the greatest bending moment is at a distance $x=\frac{3}{8}l$ from A or D. The greatest bending moment in the girder is $M_B=M_C$.

From eq. 4:

Slope at A =

$$T_{-1}=\frac{-M_Bl_1}{6EI}+\frac{w_1l_1^3}{12EI}-\frac{w_1l_1^3}{24EI}.$$

Slope at B, in span BC =

$$=T_1=-\frac{1}{3}\frac{M_Bl}{EI}-\frac{M_Bl}{6EI}+\frac{wl^3}{12EI}-\frac{wl^3}{24EI}=-\frac{M_Bl}{2EI}+\frac{wl^3}{24EI}.$$

From eq. 2:

Deflection in span AB or CD at distance x from A or D =

$$v=T_{-1}x-\frac{R_1x^3}{6EI}+\frac{wx^4}{24EI}.$$

Deflection in middle span at distance x from B or C =

$$v=T_1x-\frac{F_1x^3}{6EI}+\frac{M_Bx^2}{2EI}+\frac{wx^4}{24EI}.$$

EXAMPLE III. — *Given a continuous girder of three equal spans, loaded uniformly over its whole length with w lbs. per linear unit; to find the reactions of the supports, the bending moments and the deflections in the different spans.*— Here $w=w_1$, and $l=l_1$, and making these substitutions in the equations of Case III, we have

$$M_B=\frac{wl^2}{10} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (37)$$

$$R_1=R_4=\tfrac{4}{5}wl \quad . \quad . \quad . \quad . \quad . \quad (38)$$

$$R_2=R_3=\tfrac{11}{10}wl \quad . \quad . \quad . \quad . \quad . \quad (39)$$

Bending moment in span AB or CD at distance x from A or D =

$$M=-\tfrac{4}{5}wlx+\frac{wx^2}{2}.$$

Greatest bending moment in end spans is at the distance $\frac{4}{5}l$ from the abutments, or

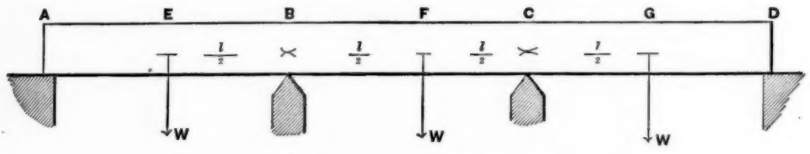
$$M=-\tfrac{2}{25}wl^2 \quad . \quad . \quad . \quad . \quad (40)$$

Maximum deflection in span BC equals deflection at the center =

$$v=\frac{wl^4}{1920EI} \quad . \quad . \quad . \quad . \quad . \quad (45)$$

CASE IV.

Continuous girder of three equal spans, with a concentrated load, W, *at the center of each span, and a distributed load of* w *lbs. per linear unit over its whole length:*



Bending moment in middle span at distance x from B or C =

$$M=\frac{wl^2}{10}-\frac{wlx}{2}+\frac{wx^2}{2}.$$

The greatest bending moment in middle span is where $x=\frac{l}{2}$, and equals

$$M=-\frac{wl^2}{40} \quad . \quad . \quad . \quad . \quad (41)$$

Hence the greatest bending moment in the girder is at B and C, and equals

$$\frac{wl^2}{10}.$$

Slope at A =

$$T_{-1}=\frac{wl^3}{40EI}.$$

Deflection in span AB or CD at distance x from A or D =

$$v=\frac{wl^3x}{40EI}-\frac{wx^3l}{15EI}+\frac{wx^4}{24EI} \quad . \quad . \quad . \quad (42)$$

This is greatest when $x=.44604\ l$, or maximum deflection in span AB or CD=

$$v=.006884\frac{wl^4}{EI} \quad . \quad . \quad . \quad . \quad . \quad (43)$$

Slope at B, in span BC =

$$T_1=-\frac{1}{120}\cdot\frac{wl^3}{EI}.$$

Deflection in span BC at distance x from B or C =

$$v=-\frac{wl^3x}{120EI}-\frac{wlx^3}{12EI}+\frac{wl^2x^2}{20EI}+\frac{wx^4}{24EI} \quad (44)$$

Let l = length of each span.
" w = distributed load per linear unit over each span.
" W = concentrated load at center of each span.
" $R_1=R_4$, $R_2=R_3$, denote the reactions of the supports at A, D, B and C respectively.

Take origin at B, then $t=o$; $M_0=M_B$; $M_1=M_C=M_B$;

$$m_1=m_{-1}=\frac{wl^2}{2}+\frac{Wl}{2}\ ;\ n_1=n_{-1}=\frac{l^4}{2EI}\ ;$$

$$q_1=q_{-1}=\frac{l^3}{6EI};\ V_1=V_{-1}=\frac{wl^4}{24EI}+\frac{Wl^3}{48EI};$$

and

$$o=-\tfrac{2}{3}\frac{M_Bl^3}{EI}-\frac{M_Bl^3}{6EI}+\frac{wl^5}{6EI}+\frac{Wl^4}{6EI}-\frac{wl^5}{12EI}-\frac{Wl^4}{24EI};$$

or

$$M_B=\frac{wl^2}{10}+\frac{3}{20}Wl \quad . \quad . \quad . \quad (46)$$

Shearing force at A or D =

$$R_1=R_4=\frac{-M_B+m_1}{l}=\frac{2}{5}wl+\frac{7}{20}W \quad . \quad (47)$$

Shearing force just to left of B, or right of C =

$$F_{-1}=\frac{M_B+\frac{wl^2}{2}+\frac{Wl}{2}}{l}=\tfrac{3}{5}wl^2+\tfrac{13}{20}Wl.$$

Shearing force just to right of B, or left of C =

$$F_1=\frac{M_B-M_C+m_1}{l}=\frac{wl}{2}+\frac{W}{2}$$

$R_2 = R_3 = F_{-1} + F_1 = \frac{11}{40} wl + \frac{3}{20} W$ . . (48)

Shearing force in section AE at distance x from A

$$= -R_1 + wx.$$

Shearing force in section EB at distance x from A

$$= -R_1 + wx + W.$$

Shearing force in section BF at distance x from B

$$= -F_1 + wx.$$

Shearing force in section FC at distance x from B

$$= -F_1 + wx + W.$$

Bending moment in section AE at distance x from A

$$= -R_1 x + \frac{wx^2}{2}.$$

Bending moment in section EB at distance x from A

$$= -R_1 x + \frac{wx^2}{2} + W\left(x - \frac{l}{2}\right).$$

Bending moment in section BF at distance x from B

$$= M_B - F_1 x + \frac{wx^2}{2}.$$

The greatest bending moment in middle span is when $x = \frac{l}{2}$, hence

$$M = -\frac{wl^2}{40} - \frac{Wl}{10} \quad . \quad . \quad . \quad . \quad (49)$$

Bending moment at center of span AB or CD (not necessarily the greatest bending moment in span)=

$$M = -\frac{11}{40} wl^2 - \frac{7}{20} Wl \quad . \quad . \quad (50)$$

Slope at A=

$$T_{-1} = -\frac{M_B l}{6EI} + \frac{wl^3}{12EI} + \frac{Wl^2}{12EI} - \frac{wl^3}{24EI} - \frac{Wl^2}{48EI}$$

$$= \frac{wl^3}{40EI} + \frac{3}{80} \cdot \frac{Wl^2}{EI}.$$

Deflection in section AE at distance x from A=

$$v = T_{-1} x - \frac{R_1 x^3}{6EI} + \frac{wx^4}{24EI} = \frac{w}{120EI}$$

$$(3l^3 x - 8x^3 l + 5x^4) + \frac{W}{120EI}\left(\frac{9l^2 x}{2} - 7x^3\right) \quad (51)$$

Deflection in section EB at distance x from A=

$$v = T_{-1} x - \frac{R_1 x^3}{6EI} + \frac{wx^4}{24EI} + \frac{W\left(x - \frac{l}{2}\right)^3}{6EI}$$

$$= \frac{w}{120EI}(3l^3 x - 8x^3 l + 5x^4) +$$

$$\frac{W}{120EI}\left\{\frac{9l^2 x}{2} - 7x^3 + 20\left(x - \frac{l}{2}\right)^3\right\} \quad (51a)$$

Deflection at center of end spans=

$$v = \frac{13}{1920} \cdot \frac{wl^4}{EI} + \frac{11}{960} \cdot \frac{Wl^3}{EI} \quad . \quad (52)$$

Slope at B, in span BC=

$$T_1 = -\frac{1}{3}\frac{M_B l}{EI} - \frac{M_C l}{6EI} + \frac{wl^3}{12EI}$$

$$+ \frac{Wl^2}{12EI} - \frac{wl^3}{24EI} - \frac{Wl^2}{48EI};$$

$$= -\frac{1}{120} \cdot \frac{wl^3}{EI} - \frac{1}{80} \cdot \frac{Wl^2}{EI}$$

Deflection in section BF at distance x from B=

$$v = T_1 x - \frac{F_1 x^3}{6EI} + \frac{M_B x^2}{2EI} + \frac{wx^4}{24EI}$$

$$= \frac{w}{120EI}(5x^4 - l^3 x + 6l^2 x^2 - 10lx^3)$$

$$+ \frac{W}{120EI}(9lx^2 - \tfrac{3}{2} l^2 x - 10x^3) \quad . \quad (53)$$

Deflection at center of middle span=

$$v = \frac{wl^4}{1920EI} + \frac{Wl^3}{480EI} \quad . \quad . \quad (54)$$

The above four cases are the principal cases met with in building construction, and any other case can be solved in a similar way without much difficulty. For convenience in using these formulæ, we will give a summary of those most frequently needed in actual practice.

SUMMARY OF THE MORE USEFUL FORMULÆ.

I. *Continuous girders of two spans.*

a. Uniformly distributed load of w lbs. per linear unit over both spans.

Length of left span $= l_1$; length of right span $= l$.

Reaction of left abutment=

$$R_1=\frac{w}{2}\left\{l_1-\frac{l^3+l_1^3}{4l_1(l+l_1)}\right\} \quad . \quad . \quad (55)$$

Reaction of middle support=

$$R_2=w(l_1+l)-R_1-R_3.$$

Reaction of right abutment=

$$R_3=\frac{w}{2}\left\{l-\frac{l^3+l_1^3}{4l(l+l_1)}\right\} \quad . \quad . \quad (56)$$

Greatest bending moment in girders is at the middle point of support, and equals

$$M=\frac{wl^3+wl_1^3}{8(l+l_1)} \quad . \quad . \quad . \quad . \quad (57)$$

When $l=l_1$, greatest deflection in either span=

$$v=.005416\frac{wl_4}{EI} \quad . \quad . \quad . \quad . \quad (22)$$

b. Concentrated load at center of left span of W_{-1} lbs., and at center of right span of W_1 lbs.
Length of either span=l.
Reaction of left abutment=

$$R_1=\frac{13W_{-1}-3W_1}{32} \quad . \quad . \quad (27)$$

Reaction of middle support=

$$R_2=\tfrac{11}{16}(W_1+W_{-1}) \quad . \quad . \quad (28)$$

Reaction of right abutment=

$$R_3=\frac{13W_1-3W_{-1}}{32} \quad . \quad . \quad (29)$$

Greatest bending moment in the girder is at the middle support, and equals—

$$M=\tfrac{3}{32}l(W_1+W_{-1}) \quad . \quad . \quad (26)$$

Deflection at center of left span=

$$v=\frac{(23W_{-1}-9W_1)l^3}{1536EI} \quad . \quad (32)$$

Deflection at center of right span=

$$v=\frac{(23W_1-9W_{-1})l^3}{1536EI} \quad . \quad . \quad (33)$$

When there is both a distributed and a concentrated load the reactions of the supports, bending moments, and deflections, will be the sum of those for a distributed load and those for a concentrated load, as shown by the formulæ of Cases II. and IV.

II. *Continuous girder of three spans:*

a. Uniformly distributed load of w lbs. per linear unit over each span.
Length of each end span $=l_1$; length of middle span=l.
Reaction of either abutment=

$$R_1=R_4=\frac{w}{2}\left\{l-\frac{l^3+l_1^3}{2l_1(3l+2l_1)}\right\} \quad . \quad (58)$$

Reaction of either central support=

$$R_2=R_3=\frac{w}{2}\left\{(l+l_1)+\frac{l^3+l_1^3}{2l_1(3l+2l_1)}\right\} \quad (59)$$

Greatest bending moment in the girder is at either of the central supports, and equals

$$M=\frac{wl^3+wl_1^3}{4(3l+2l')} \quad . \quad . \quad . \quad . \quad (60)$$

When $l=l_1$,
Deflection at center of middle span=

$$v=\frac{wl^4}{1920EI} \quad . \quad . \quad . \quad . \quad (45)$$

Greatest deflection in end spans=

$$v=.006884\frac{wl^4}{EI} \quad . \quad . \quad . \quad (43)$$

b. Concentrated load of W lbs. at center of each span.
Length of each span=l.
Reaction of either abutment=

$$R_1=R_4=\tfrac{7}{20}W \quad . \quad . \quad . \quad (61)$$

Reaction of either central support=

$$R_2=R_3=\tfrac{13}{20}W \quad . \quad . \quad . \quad (62)$$

Greatest bending moment in the girder is at either of the central supports, and equals

$$M=\tfrac{3}{20}Wl \quad . \quad . \quad . \quad . \quad . \quad (63)$$

Deflection at center of middle span=

$$v=\frac{Wl^3}{480EI} \quad . \quad . \quad . \quad (64)$$

Deflection at center of end spans=

$$v=\frac{11}{960}\cdot\frac{Wl^3}{EI} \quad . \quad . \quad . \quad (65)$$

Formulæ 55, 56, 57, 58, 59, 60 and 61 are obtained from 8, 9, 7, 35, 36, 34 and 47, respectively, by making $w_1=w$. Formulæ 61, 62, 63, 64 and 65 are obtained from 47, 48, 46, 54 and 52, respectively, by making $w=o$.

VERIFICATION OF FORMULÆ.

Formulæ 28, 46 and 63 were tested by loading a small steel beam so as to fulfill the condition of the formulæ, and measuring the reactions of the support by means of a spring balance, which was used for the support.

The results obtained from several tests did not vary more than one-half of one per cent. from the values given by the formulæ.

Formulæ 32, 33, 64 and 65 were tested by measuring the deflections of a steel bar $\frac{1}{4}$ inch square, supported on knife edges 12 inches apart, and loaded at the centers of the spans with loads varying from 5 to 25 lbs., and comparing them with the deflection of a beam, cut from the same bar, supported at each end, and loaded with the same loads as the continuous beam, the span being also 12 inches.

The greatest difference between the actual deflections and those given by the formulæ was $7\frac{1}{2}$ per cent., while several values agreed exactly, although it was difficult to arrange the experiments so as to have all of the conditions perfectly fulfilled. We think, however, that these experiments are sufficient to prove the truth of the theory of continuous girders, as applied to small beams at least, and also the accuracy of the formulæ.

For those who care to compare the formulæ contained in this paper with such as can be found elsewhere, we will state that formulæ 7 and 8 agree respectively with formulæ 65 and 66, of "Wheeler's Treatise on Civil Engineering," prepared for the use of the cadets at West Point; formulæ 19, 21, 38, 39, 42 and 44 agree with formula 162, 173, 188, 189, 173 and 187 of "Stoney's Theory of Strains," edition of 1873; and formula 22 is the same as formula 560 of "Moseley's Engineering and Architecture," edited by Mahan.

THE LATEST ASPECT OF THE BRAKE QUESTION.

From "The Engineer."

We told our readers that it was rumored that a very important step was about to be taken by the London and Northwestern Railway Company. According to the reports which have reached us, that company has decided to adopt a new system of continuous brake, and it is hinted that its example will be followed by other companies, so that the carriages and engines of any one line can run over other roads; and trains may be made up of the coaches of all the companies without interfering with the action of the brakes. This proposal contemplates the expenditure of a great deal of money; and the position of the companies is so important, that whatever brake they adopt in common is pretty certain to be extensively, if not universally, adopted, to the exclusion of all others by the remaining railway companies of the United Kingdom. It is therefore of the last importance to the future of the railway system, that if the rumor be true and a selection is to be made, it should be the best possible; and that it should be made under circumstances at once the most favorable, to the rejection of what is bad, weak, or defective, and most likely to secure the adoption of that brake which is the most trustworthy and efficient. A mistake committed now might cause a very prejudicial effect for years to come in the matter of dividends. Let us consider what are the actual conditions obtaining.

The movement appears to have originated with the London and Northwestern Railway Company. The Clark and Webb brake, after being patched up and modified time and again, is now moribund. It has almost invariably been found useless when it was wanted; and the recent accident on the North London line may be said to have given it the *coup de grace*. It has been condemned long ago in the strongest terms by the Board of Trade; and the "emergency brake," of the London and Northwestern Railway, has been the subject for a good many pleasantries among railway men. Mr. Moon has, nevertheless, told the shareholders, over and over again, that they had got an admirable brake, and this at the time that

the said brake was indirectly causing a good deal of destruction of their property, and bringing about annoying claims for compensation. If any of our readers fancy that we are drawing an exaggerated picture, he has but to turn to the Board of Trade reports to see that we have said not nearly so much in condemnation of the system as it deserves. In the selection of the new system, Mr. Moon and Mr. Webb will no doubt have a voice, and a very important and even authoritative voice, too. But may we not ask if either one gentleman or the other is qualified to make a selection? Mr. Moon is the chairman of the company, and is not an engineer; but even a chairman has ample opportunities of knowing what the performance of the mechanical elements of the system which he controls is like. Mr. Moon has either been unable or unwilling to learn what practice with the Clark and Webb brake had to teach; and it is only hard fate, and the grim logic of facts, which have at last compelled him to reject the brake which he has assured the world over and over again was as good a brake as could be had. Mr. Moon has not proved that he possesses any qualifications for selecting a brake. The case for Mr. Webb is not much better. He flatly opposed his own opinion to that of all the other railway officials in the kingdom, not one of whom would adopt his brake on a fast main line train, and he has manifested throughout a want of perception of what was needed in a brake, which does not encourage us to hope that he will make a better selection in future than he has done in the past.

The selection must be made within a very narrow circle. We do not mean to say a syllable in disparagement of several very ingenious devices which have been before the world for a greater or lesser period; but in truth there are but two systems from which a union of railway companies such as that of which we write can choose. These are the Westinghouse automatic, and the automatic vacuum brakes. It would be affectation on our part to pretend at this moment that it would be unfair to express an opinion of our own on the merits of the two systems. At such a time it is the duty of those who can influence public opinion to say what they think; and we have no hesitation in asserting that any great union of railway companies ought to adopt the automatic pressure brake. Let it be clearly understood that we not only willingly admit but gladly believe that there are excellent automatic vacuum brakes in the market. Those of Mr. Sanders, Mr. Aspinwall and Mr. Eames are all ingenious and all efficient, but they are not as efficient as the Westinghouse brake, and they have not received that cosmopolitan approval which has been bestowed on the Westinghouse brake. We have only to look to the records of public trials to see that as a train stopper the Westinghouse brake has never been beaten; and there is no other brake in the world employed to anything like the same extent, or with which anything like the same experience has been had. We have no desire to give figures here. They are very dry reading at the best of times, and we doubt that we should quite convey to our reader's mind what we wish him mentally to absorb, by a statement of the number of miles of line in this country and abroad worked with Westinghouse brakes. It will be more to the purpose if we explain that railway company after railway company has adopted the system, after the most careful deliberation, and that at this moment the Westinghouse Brake Company is making and fitting up probably ten brakes for every one made on any other system. So far as the Board of Trade and other reports go, the favor enjoyed by the system is justified by facts.

Dealing still with rumor, we hear that the London and Northwestern Company is likely to adopt a modification of the automatic vacuum brake. If this be done a mistake will be committed. In saying this we do not mean to say that the brake in question is not good and efficient. But even if we admitted, which we do not, that it was as good as the Westinghouse brake; it would still be the duty of the officials of great railway companies to select of the two that brake concerning which most was known, and about which the largest experience had been obtained. Two men, candidates for a given post, may be equally clever, equally well educated, and apparently equally competent to perform the duties required. But a prudent employer in

making his selection would choose the man who had been longest employed, and whose operations had extended over the largest area. This is the way of the world, and it ought to be the way with brakes as with men. It appears to us that the Westinghouse brake possesses this great advantage over all other brakes in the market, that concerning it everything which can be learned is known; whereas a great deal of information has yet to be acquired concerning all the other continuous brakes before the public. The Westinghouse brake is no longer experimental. The only other system of which the same thing can be said is Smith's vacuum brake, and that does not comply with the demands of the Board of Trade; and has been finally condemned as insufficient for the purposes of any great railway company. Under the circumstances we cannot see that the railway company we have named can do wrong if it follows the example recently set in France by a powerful company, and adopts the Westinghouse system. But if it does not feel disposed to do this, then it would be advisable, we think, to consult the railway department of the Board of Trade, and obtain a definite expression of opinion from its officers. On the whole we believe that the balance of advantage would be in favor of the course we urged last week, namely, the appointment of a small committee, in which the directors of various companies should be represented, and which should include a couple of engineer officers from the Board of Trade. Before this committee evidence might be given by the advocates of the different systems, and reports, facts and figures might be studied. The functions of the committee would be limited of course to recommending the adoption of one system out of the two or three from which alone a selection can be made; and it would be more satisfactory to all concerned if a choice of such vast importance was made in this way than by three or four locomotive superintendents, who, whatever the course they adopt, will find that they have been placed in a disagreeable and invidious position, and involved in a responsibility from which they might well shrink with annoyance, if not alarm.

THE THOMAS-GILCHRIST PROCESS.

From "Iron."

"My opinion is, that the success of the basic process is assured as replacing the puddling furnace, *in toto* or in part, as a means of manufacturing soft metal." Such is the conclusion—substantially the same as that arrived at by Professor Tunner—of the eminent and sagacious French chemist and metallurgist, M. Pourcel, of Terrenoire, in an article written last autumn (and lately reproduced in our columns) under the influence of the discussions and exhibitions of dephosphorizing practice which formed the leading feature of the Dusseldorf meeting of the Iron and Steel Institute. This very remarkable expression of opinion is, however, qualified by the uncertainty expressed by M. Pourcel as to whether or no the new process will successfully rival the old acid Bessemer process in the manufacture of hard metal. We may note, however, that, despite the partial hesitation expressed by M. Pourcel, no less than five-and-twenty Bessemer converters on the Continent are now engaged in the manufacture of not only soft but hard steel by the Thomas-Gilchrist process. In face of these decisive opinions from such men as M. Pourcel, Von Tunner, Trasenster, and others, and the still more significant fact of such an extensive practical working, the position of English ironmakers—who have up till now been left far behind by their foreign rivals in the adoption of the basic process—is both anomalous and dangerous, and the sooner they endeavor to appreciate the exact value of the new departure in its economic bearings the better. It is somewhat remarkable that, up to the present time, no serious effort has been made to examine in detail the economic aspect of dephosphorization in

its bearing on English ironmaking, though we have had exhaustive treatises on its bearing on Austrian, French, German and Belgian metallurgy. This deficiency, it is proposed here to attempt to supply, so as to do something towards clearing away the cloud of prejudice and uncertainty which has gathered about the subject, by dealing solely with facts and figures.

The points which seem on all hands to be substantially admitted are:

(1) That, in the manufacture of soft steel (or ingot iron), a metal may be made as pure, or purer, by the new Bessemer or Siemens process from phosphoric pig, as, by the old processes, is made from hematite pig.

(2) That there are no technical difficulties in carrying out the process on a large scale.

The points that were still, to a certain extent, under discussion at the time of the Dusseldorf meeting, but on which much light has since been thrown, were:

(3) Whether hard steel could be manufactured by the new process without special cost and difficulty.

(4) The precise cost of converting phosphoric pig into steel, as compared with the cost of conversion of non-phosphoric pig. Since last September, Messrs. Bolckow, Vaughan & Co., Messrs. Schneider, the Angleur, Rhenish. Höerde, Bochum, and other companies, have, it is understood, proved to the satisfaction of nearly all the railway companies, both of the Continent and England, that rails manufactured by the lime process can be made quite as hard as by the old Bessemer process; so that the assertion that the new steel was only fit for replacing wrought iron has become untenable, and has been tacitly abandoned; and the manufacturers of basic steel are now as willing to accept specifications for four-tenths per cent. of carbon as for two-tenths. The best opinion among engineers continues, however, to incline more and more to the belief that safety and durability in rails are rather to be found in soft than in hard steel; and it is probable that the American formula, based on Dr. Dudley's latest researches, prescribing about three-tenths of carbon, and not more than four-hundredths per cent. of silicon, will be more and more widely adopted by engineers. In Germany the tendency to prefer soft to hard steel is even more marked than elsewhere; and the tests prescribed practically limit steelmakers to from two to three-tenths per cent. of carbon for rails, and a still smaller proportion for sleepers. The question whether steel with over five-tenths per cent. of carbon can be made as readily by the new as by the old process is still one on which, as M. Pourcel says: "We are not in a position to speak confidently." As, however, it is doubtful if five per cent. of the three million and odd tons of Bessemer steel made in 1880 contained anything like five-tenths of carbon, this consideration is not an important one. There is, however, one great advantage claimed, and seemingly with justice, for the new metal, which is certainly not possessed by ordinary Bessemer steel—that is, the far smaller proportion—or, rather, complete absence—of silicon, an element which, as stated by a well-known steelmaker at a recent meeting of the Iron and Steel Institute, often gives more trouble than phosphorus. We may take it that, if the new process may be relied on, as appears to be the case, to produce steel with any content of carbon between five hundredths and five-tenths per cent., that practically ninety-nine hundredths of the ground open to the steelmaker is covered. The question of the real position of the Thomas-Gilchrist process is, therefore, after all, narrowed down to a question of "What will it cost?" It has always been admitted, even by its friends, that, assuming the price of pig to be equal, the basic process at present costs more than the acid. The point now to be determined is, as M. Pourcel says, the necessary margin of cost between hematite and phosphoric pig to allow of the latter competing with the former as a raw material for steelmaking. Another, and not less important question, hangs, however, on this one of the cost of conversion by the lime process. The future of the iron trade depends in a large measure upon whether the manufacture of soft ingots by the basic process costs more or less than the manufacture of puddled bars by puddling from pig iron of equal value. The proper appreciation of the right answer to this question is a matter of the highest import-

ance to British industry; and it would seem that we have now all the elements to enable us to form an independent and reliable opinion; M. Pourcel's paper forming a convenient basis for the investigation. It would appear that what may be called the excess costs of the new process may be classed under four heads, viz., cost of lime, cost of lining, cost of waste and extra labor, and cost of extra plant required to prevent reduced make. From the data given in M. Pourcel's paper and elsewhere, it seems that about 3½ cwt. of lime are used for additions per ton of steel produced. Now, the average cost of burnt lime in Cleveland, Sheffield, Wales, Staffordshire, Northamptonshire, and Lincolnshire varies between 7s. and 12s.; the mean value being about 9s. 6d. per ton. Taking, however, 10s. per ton for the cost of lime, we find the lime additions per ton of steel will cost 1s. 9d. The slag produced, containing from 10 to 20 per cent. of phosphoric acid and about 60 per cent. of lime, is at present used as a flux in the blast furnace, but its obvious ultimate destination is to be used as a manure, as phosphate of lime is at present worth from 1s. to 3s. per unit. Whatever, however, may be the ultimate value of the slag, whether as a flux or a manure, it will be safest to, at present, treat it as nil. With regard to the cost of lining, it is best to examine the facts rather than M. Pourcel's curious deductions. In one paragraph M. Pourcel says:

"At Ruhrort the vessel stops after forty blows, for repairs, whether general or partial I am unable to say." He then assumes that the whole lining is renewed (having previously stated that he did not ascertain if this were the case or not), and states that M. Transenter's figures on the cost of lining are inadmissible, as they do not agree with the assumption (made by M. Pourcel, as he himself states, in perfect ignorance) that the whole lining is repaired. Now, if M. Pourcel had taken the trouble to ask the courteous managers of the Rhenish Works he would have been told, as were others of their visitors, that the total consumption of both linings and bottoms amounted to 50 kilos, or, say 1 cwt. per ton of steel produced. Now, it appears that the price now charged in England (by the Raisby Hill Lime Company) for lime bricks is about 45s. a ton, adding 20s. a ton as a liberal allowance for labor and carriage, we have 3s. 3d. for the actual total cost of basic linings and bottoms. This is, however, probably considerably in excess of the actual cost to such firms as Bolckow, Vaughan & Co., who manufacture their own basic material. Now, the ordinary cost for linings and bottoms in the old Bessemer process varies from 1s. to 1s. 9d. a ton, which leaves the present excess cost for the new process at about 2s. per ton.

It seems admitted on all sides that an old Bessemer plant worked on phosphoric pig will not, on account of the smaller durability of the lining, be capable of the same output as when working on non-phosphoric pig. Arrangements have, therefore, to be made for duplicating or removing the vessels or vessel shells. Fortunately, however, this is the least expensive part of the plant, the blowing and hydraulic machinery having the same productive capacity on the one system as the other. The duplication or removal of the vessels, either of which devices will render the output with the basic system at least as great as with the acid, has been found to add from £3,000 to £6,000 to the cost of a Bessemer plant. Now, 10 per cent. for interest and sinking fund, on the larger of these sums, equals £600 a year, or, on a make of 2,000 tons a week, rather less than 1½d. per ton. If the make of modern American plant—say 3,000 tons a week—were attained, this item would sink to 1d. per ton. We may, however, take it, for simplicity, as 2d. per ton of steel made.

On the question of waste, we are, as M. Pourcel remarks, still without any precise figures. Collating, however, the figures given by M. Pourcel and Messrs. Richards, Massenez, Cooper, Pink and others, we find that the waste on the new process varies between 11 and 18 per cent., the mean being 14½ per cent. It will, however, be perhaps safest to assume for the present a waste of 15½ per cent. for the basic process and 12½ per cent. for the acid, the latter being, perhaps, rather below the English and American average. Now, a waste of 12½

per cent. on pig worth 60s. a ton, the present minimum price of hematite, represents a cost of 7s. 6d., while a waste of 15½ per cent. on pig worth 40s. (the present normal price of Cleveland pig) represents a cost of only 6s. 3d. In other words, on the item of loss, the net gain on working Cleveland pig at Middlesbrough over Cumberland hematite at Barrow, or Workington, is 1s. 3d. per ton of steel.

The exact cost of the extra labor required in the basic system cannot be very precisely ascertained; we may, however, arrive at the figures pretty closely. We have first to consider the cost of throwing, say, 4 cwt. of lime into the converter, secondly, of removing 4 cwt. extra of slag.

Now, the cost of moving 1 ton of material in ironworks, as, for instance, in loading or unloading, is usually reckoned at 2d. per ton. The cost of moving 8 cwt. of slag and lime may, therefore, be taken at approximately 1d. To this we may probably add 6d. a ton, for contingencies and extra labor on repairs.

Summarizing these figures, we obtain the following as the extra cost on producing a ton of steel by the Thomas-Gilchrist process:

	s.	d.
3½ cwt. of lime, at 10s. per ton,....	1	9
Extra cost of basic lining over siliceous lining.....	2	0
Interest and sinking fund on extra plant required.....	0	2
Extra labor and incidental expenses..	0	7
Deduct smaller money value of 15½ per cent. loss on pig at 40s. over 12½ per cent. loss on pig at 60s....	1	3
Net extra basic cost.....	3	3

Now this conclusion differs very materially from that of M. Pourcel and other continental critics. The reasons for this difference appear to be the following:

It was early assumed, on *a priori* grounds, on the Continent, that direct blast furnace metal could not be worked by the lime process, and the calculations of cost have been largely based on this assumption, thus, Von Tunner debits it with 8 fr. a ton on this account. Now, so far from this being the case, nothing but direct metal is used either at Eston or Creusot, and this with the best results. It is also assumed by M. Pourcel and M. Trasenster that a special and expensive manganiferous pig must be used, but, here again, experience has falsified the predictions of very able metallurgists, and Mr. Richards informs us that ordinary Cleveland forge and white pig made from Cleveland stone alone has been used at Eston for the past six months with perfect success. Finally, the consumption and price of basic lining materials have both been placed at a far higher figure than later experience warrants. Thus, we learn that at all the Continental works now working the lime process the average life of the basic bottoms considerably exceeds the average duration of gannister bottoms in England, while the cost of basic lining material in England is little more than half the price stated by M. Pourcel to be paid in Germany.

We are thus irresistibly led to two conclusions. First, that wherever the cost of phosphoric pig, moderately low in silicon and sulphur, is more than 7s. or 8s. a ton less than the cost of hematite Bessemer pig, the basic process will be inevitably sooner or later adopted. Second, that steel ingots can at this moment be produced for less than puddled bars everywhere, since it is generally admitted that, using pig iron of equal value, the cost of producing puddled bars is at least 6s. a ton greater than that of producing steel ingots.

THE Russian Finance Minister has just concluded an inquiry through the Department of Manufacture and Commerce into the state of the Russian commercial fleet. On the 1st of January this fleet stood as follows: The ports of the White Sea had 11 steamers of 916 lastels tonnage, 575 sailing vessels of 14,512 lastels; Baltic ports, 63 steamers of 9,539 lastels, and 578 sailing vessels of 43,771 lastels; Black Sea and Sea of Azof, 171 steamers of 29,564 lastels, and 1,964 sailing vessels of 76,091 lastels; Caspian, 36 steamers of 5491 lastels, and 1,004 sailing vessels of 49,656 lastels; Pacific Ocean, 15 steamers of 10,000 lastels. In all 296 steamers of 55,510 lastels, and 4,121 sailing vessels of 184,130 lastels. Of the total number—4,417—1,196 are employed in deep-sea navigation, and 3,221 in the coasting trade. Of the total number, 3,695 have been built in Russia and 722 abroad.

THE POLARISCOPE.

By J. P. BATTERSHALL, Ph. D.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

DURING the past quarter of a century the importance of scientific research and discovery, in their practical bearings on subjects intimately connected with the interests of manufacturers, has become more and more clearly demonstrated. Perhaps the most striking illustration of this fact is afforded by the instrument commonly known as the Polariscope (but more correctly termed the Saccharimeter), which is at present almost universally employed by sugar merchants, for the purpose of determining the actual value of their merchandise. This instrument has received somewhat frequent mention of late in the newspapers; an explanation of the salient principles involved in its construction may, therefore, be of interest to the general reader. In order to convey an intelligent idea of the physical laws which govern the practical working of the Polariscope, it will first be necessary to refer to the subject of the polarization of light. The transformation of ordinary into polarized light is best effected either by reflection from a glass plate at an angle of about 56°, or by what is known as double refraction. The former method can be illustrated by Fig. 1, which represents two tubes, B and C, arranged so as to allow the one to be turned round within the other. Two flat plates of glass, A and P, blackened at the backs, are attached obliquely to the end of each tube at an angle of 56°, as represented in the figure. The tube B, with its attached plate, A, can be turned round in the tube C without changing the inclination of the plate to a ray passing along the axis of the tube.

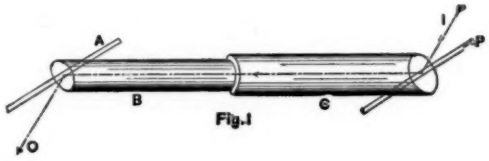


Fig. 1

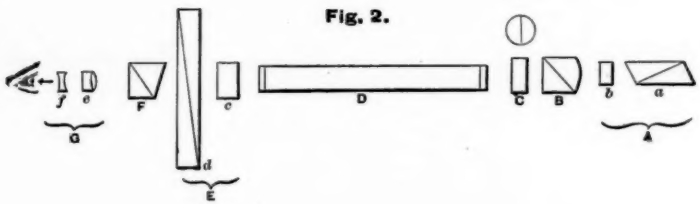
If a candle be now placed at I, the light will be reflected from the plate P through the tube, and, owing to the particular angle of this plate, will undergo a certain transformation in its nature, or, in other words, become "polarized." So long as the plate A retains the position represented in the figure, the reflected ray would fall in the same plane as that in which the polarization of the ray took place, and an image of the candle would be seen by an observer stationed at O. But, suppose the tube B to be turned a quarter round; the plane of reflection is now at right angles to that of polarization, and the image will become invisible. When the tube B is turned half way round, the candle is seen as brightly as at first; at the third quadrant it disappears, until, on completing the revolution of the tube, it again becomes perfectly visible. It is evident that the ray reflected from the glass plate P has acquired properties different from those possessed by ordinary light, which would have been reflected by the plate A in whatever direction it might have been turned.

If a ray of common light be made to pass through certain crystals, such as calc spar, it undergoes double refraction, and the light transmitted becomes polarized. The arrangement known as Nichol's prism, which consists of two prisms of calc spar, cut at a certain angle and united together by means of Canada balsam, is a very convenient means of obtaining polarized light. If two Nichol's prisms are placed in a similar position, one behind the other, the

light polarized by the first (or polarizing) prism passes through the second (or analyzing) prism unchanged; but if the second prism be turned until it crosses the first at a right angle, perfect darkness ensues. While it would exceed the limits of the present article to enter fully upon the theoretical explanations which are commonly advanced concerning the cause and nature of this polarized, or transformed light, it may be well to state here that common light is assumed to be composed of two systems of beams which vibrate in planes at right angles to each other, whereas polarized light is regarded as consisting of beams vibrating in a single plane only. If, now, we imagine the second Nichol's prism to be made up of a series of fibers or lines, running only in one direction, these fibres would act like a grating and give free passage to a surface like a knife blade only when this is parallel to the bars, but would obstruct it if presented transversely. This somewhat crude illustration will, perhaps, serve to explain why the rays of light which have been polarized by the first Nichol's prism are allowed to pass through the second prism when the two are placed in a similar position, and why they are obstructed when the prisms are crossed at right angles, it being remembered that in a polarized ray the vibrations of the beams of light take place in a single plane.

Suppose we place between the two Nichol's prisms, while they are at right angles, a plate cut in a peculiar manner from a crystal of quartz—we will discover that rays of light now pass through the second prism, and that the field of vision has become illuminated with beautiful colors—red, yellow, green, blue, etc., according to the thickness of the quartz plate used. On *turning* the second Nichol's prism on its axis these colors will change and pass through the regular prismatic series, from red to violet, or the contrary, according to the direction of the rotation produced by the intervening plate. Quartz, therefore, possesses the remarkable property of rotating the plane of polarization of the colored rays of which light is composed; and it has been discovered that some plates of this mineral exert this power to the right, others to the left; that is, they possess a right or left-handed circular polarization. Numerous other substances, including many organic compounds, possess this property of causing a rotation—either to the right or left—of a plane of polarized light. For example, solutions of cane sugar and ordinary glucose cause a right-handed rotation, whilst uncrystalized sugar exerts a left-handed rotation. The extent of this power is directly proportional to the concentration of the solutions used, the length of the column through which the ray of polarized light passes being the same. It follows that on passing polarized light through tubes of the same length which are filled with solutions containing different quantities of impure cane sugar, an estimation of the amount of pure cane sugar contained in the tubes can be made by determining the degree of right-handed rotation produced; and it is upon this fact that the application of the polariscope in sugar analysis is based. The optical portions of the most improved form of the Polariscope—that known as the Ventzke-Scheibler—are represented by Fig. 2.

Fig. 2.



The light from a gas burner enters at the extremity of the instrument and first passes through the "regulator A," which consists of the double refracting Nichol's prism *a* and the quartz plate *b*, it being so arranged that it can be turned round its own plane, thus varying the tint of the light used, so as to best neutralize

that possessed by the sugar solution to be examined. The incident ray now penetrates the polarizing Nichol's prism B, and next meets a double quartz plate C (3.75 millimeters in thickness). This quartz plate, a front view of which is also shown in the figure, is divided in the field of vision, one-half consisting of quartz rotating to the right hand, the other half of the variety which rotates to the left hand. It is made of the thickness referred to, owing to the fact that it then imparts a very sensitive tint (purple) to polarized light, and one that passes very suddenly into red or blue when the rotation of the ray is changed. Since the plate C is composed of halves which exert opposite rotary powers, these will assume different colors upon altering the rotation of the ray. After leaving the double quartz plate the light, which, owing to its passage through the Nichol's prism B is now polarized, enters the tube D containing the solution of cane sugar under examination; this causes it to undergo a right-handed rotation. It next meets the "compensator" E, consisting of a quartz plate *c*, which has a right-handed rotary power, and the two quartz prisms *d*, both of which are cut in a wedge shape and exert a left-handed rotation. They are so arranged that one is movable and can be made to slide along the other, which is fixed, thus causing an increase or decrease in their combined thickness and rotary effect. The ray of light then passes through the analyzing Nichol's prism F, and is finally examined by means of the telescope C, with the objective *e* and ocular *f*. Fig. 3 gives a perspective view of the Ventzke-Scheibler polariscope. The Nichol's prism and quartz plate which constitute the "regulator" are situated at A and B, and can be rotated by means of a pinion connecting with the button L. The polarizing Nichol's prism is placed at C, and the double quartz plate at D. The receptacle *h* contains the tube P filled with sugar solution, and is provided with the hinged cover h', which serves to keep out the external light while an observation is being taken. The right-handed quartz plate and the wedge-shaped quartz prisms (corresponding to *c* and *d*, Fig. 2) are situated at G and at E and F, and the analyzing Nichol's prism is placed at H. When the wedge-shaped prisms have an equal thickness coinciding with that of the quartz plate *c* (Fig. 2) the left-handed rotary power of the former is exactly neutralized by the right-handed rotary power of the latter, and the field of vision seen at I is uniform in color, the opposing rotary powers of the two halves of the double quartz plates C (Fig. 2) being also equalized. But if the tube, filled with a sugar solution, is placed in the instrument, the right-handed rotary power of this substance is added to that half of the double quartz plate which exerts the same rotary effect (the other half being diminished in a like degree), and the two divisions of the plate will now appear of different colors. In order to restore an equilibrium of color, the movable wedge-shaped quartz plate E is slid along its fellow F by means of the rachet M, until the right-handed rotary power of the sugar solution is compensated for by the increased thickness of the left-handed plate, when the sections of the plate C will again ap

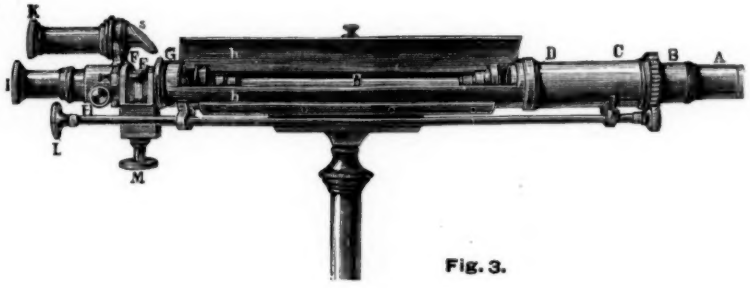


Fig. 3.

pear uniform in color. For the purpose of measuring the extent to which the unfixed plate has been moved, a small ivory scale is attached to this plate, and passes along index scale connected with the fixed plate. The degrees marked on the scale, which are divided into tenths, are read by aid of a mirror *s* attached to a magnifying glass K. When the polariscope is in what may be termed a state of equilibrium—*i. e.* before the tube containing the sugar solution has been placed in it—the index of the fixed scale points to the zero of the movable scale.

In the practical use of the Ventzke-Scheibler saccharimeter, the method adopted is essentially as follows: 13.024 grammes of the raw sugar to be tested are carefully weighed out and introduced into a flask 50 cubic centimeters in capacity; water is added, and the flask shaken until all crystals are dissolved. The solution is next decolorized by means of sub-acetate of lead, its volume made up to 50 cubic centimeters, and a little bone-black having been added if necessary, a glass tube, corresponding to P (Fig. 3), which is exactly 200 millimeters in length, and is provided with suitable caps, is completely filled with the clear filtered liquid. This is then placed in the polariscope, and protected from external light by closing the cover shown at *h'*. On now observing the field of vision by means of the telescope, it will be seen that the halves into which it is divided exhibit different colors. The screw, M, is then turned to the right until this is no longer the case, and absolute uniformity of color is restored to the divisions of the double quartz plate C (Fig. 2). The extent to which the screw has been turned, which corresponds to the right-handed rotation caused by the sugar solution, is now ascertained on reading the scale by aid of the glass K. The instrument under consideration is so constructed that, when solutions and tubes of the concentration and length referred to above are used, the reading on the scale gives directly the percentage of pure crystallizable cane sugar contained in the sample examined. For instance, if the index zero of the fixed scale points to 96.°5 on the movable scale, after uniformity of color has been obtained, the sample of sugar taken contains 96.5 per centum of pure cane sugar. The results given by the polariscope possess an accuracy rarely, if ever, attained by any other apparatus employed in the determination of practical commercial values. It may be added, in this connection, that so long as sugar is bought and sold by merchants, according to its actual saccharine strength as shown by the polariscope, the adoption of this instrument by the United States Treasury Department appears to be perfectly justifiable, so far as the question of the accuracy of its indications is concerned. It would seem that the Government simply desires to determine the true value of imported sugar by means of the most accurate method known; and this opinion is supported by the fact that the experts employed for the purpose of sugar testing are gentlemen selected by the Appraiser, Hon. James Q. Howard, solely on account of their scientific reputation and practical experience in this particular branch of work. Another strong justification for the adoption of the polariscope in the clasification of sugars is afforded by the fact that the artificial coloring of certain sugars known as "vacuum pan"—which is notoriously practiced with an intent to defraud the revenue—can be readily indicated by means of this instrument.

Attention is again being called to the formation of a permanent inoxydizable coating on iron articles. The Barff and Bower processes are very well known. A new process, devised by Mr. Ward, consists in the combined application of silicates and heat, this process being the basis of several subsequent processes for ornamenting the surface of the metal. The iron objects are coated with a silicate composition, which is applied either by means of a brush or by dipping the iron in a bath of the solution. The coating quickly dries upon the objects, which are then passed through a furnace heated according to the nature of the articles under treatment. The silicate composition is thus fused, and, it is said, absorbed into the pores of the metal, becoming homogeneous with it. Upon cooling the articles treated are found to be covered with a dull black coating.

THE ORIGIN OF THE ENGLISH MILE.

From "English Mechanic and World of Science."

An interesting paper (of which we propose to give the substance) on the subject of the English mile, was lately read to the Paris Academy, by M. Faye.

The mile of 1,609 meters, it is known, long passed as equivalent in length to a terrestrial arc of 1 minute—the degree containing 60 of these miles—in reality it contains 69.5, the error being about a sixth. This error, so long current, may have caused more than one disaster at sea. It delayed, for many years, the discovery of universal attraction. The first time the idea that the attraction of the earth retaining the moon in its orbit is the same thing as gravity, presented itself to Newton, he failed in the verification, because he then employed the mile in calculating the earth's radius. He thought he must renounce the idea, and he only returned to it, when he became acquainted much later with the measurement of a degree executed by Picard, in France.

Whence this evaluation so defective, so unfit for the purposes of navigation? The worst measures of a degree really made, like that of Posidonius, are far from presenting such errors. The English geographers must have made some mistake in taking their mile from ancient documents.

It cannot be supposed, indeed, that geographers took the first mile as a measure of the terrestrial minute. So long as navigation was limited to the Mediterranean and the western coasts of Europe, there was no occasion to study the value of this element; but when the Spaniards and Portuguese had opened up a wider range, sailors were obliged to inquire into it. The English navigator probably applied to the geographers, and the latter could not find a better course than to consult Ptolemy, the great and only authority in such matters.

Now, Ptolemy himself referred to Eratosthenes; he says he had verified his measures and found the same thing, viz., 500 stadia to a terrestrial degree. I was thus led to study Eratosthenes' measure. According to documents that are preserved, Eratosthenes appears to have measured the great meridian arc which separates the parallel of Syene and Alexandria, and he found 700 stadia to a degree. Eratosthenes was a Greek astronomer established in Alexandria 250 years, B. C. Called to Egypt and patronised by Philadelphus, he benefited by the liberality of a king, friendly to science and arts. He himself erected, at Alexandria, astronomical instruments that were very well conceived. He operated thus:

He observed at Alexandria, pretty certainly with the aid of a gnomon, the zenith distance of the sun at midday, on the day of the summer solstice, and found it 7° 12′. It is added that at Syene the bottom of certain pits was fully illuminated by the sun on that day, so that Eratosthenes concluded zero for the zenith distance of the sun. Probably, however, the learned Greek observed at Syene also with a gnomon, an instrument widely distributed in Egypt.

The amplitude 7° 12′ concluded by Eratosthenes is correct; it has, moreover, the advantage of not having been affected by refraction.

One verification is afford by the *Connaissance des Temps*, where one finds

For the latitude of Alexandria . 31°12′
" " " Syene..... 24° 5′

Difference.. 7° 7′

instead of 7°12′; the discrepance is small.

There is a second and more delicate verification. The latitude of the point at Alexandria, where Eratosthenes observed, could not differ much from that just given. Adopting it, and 7°12′ for the zenith distance of the upper limb of the sun at the summer solstice, one finds $31°12'-(7°12'+16)=23°44'$ for the obliquity of the ecliptic. Syene gives $24°5'-16'=23°49'$. Is it possible that in the year—250 the obliquity of the ecliptic was from 23° 44′ to 23° 49′? The reply is, that from 1750 to—250 are 2,000 years. At the rate of 48″ diminution in a century, the obliquity would be

23° 28′ 18″+48″×20=23° 44′. Thus the observation of Eratosthenes at Alexandria is authentic and very precise. That at Syene presents a discrepance of only 5′.

There remains the geodesic operation. Egypt was the only country of antiquity which boasted a survey. The valley of the Nile was largely peopled at this time, up to the Syene. Doubtless the survey extended thither. Eratosthenes must have had every facility for obtaining the necessary documents. A people who knew so well how to direct its monuments must, by its immense surveying operations, have known not only the distances, but the orientation. Eratosthenes would take account of the difference of longitude, 2° 59′, existing between the two cities, without requiring to determine it directly. I regard, then, the distance of 5,000 stadia, in round numbers, as being quite as serious as the other part of his operation, and as applying to the arc of meridian comprised between the parallel of the two cities.

The number 694.4 stadia was finally concluded for a degree. The Greek astronomer gives in round numbers 700 stadia. What was this stadium?

To answer this question, I calculate the arc of meridian, from Alexandria to the parallel of Syene, with the actual elements of the terrestrial ellipsoid. It is 797,760m.; accepting 5,000 stadia, we find 159.55m. for the stadium. With 600ft. to the stadium, the foot adopted by Eratosthenes would be 0.266m. It was, then, the ancient Egyptian foot, which we now estimate at 0.27m., and, in fact, it was with this foot that the survey of Egypt seems to have been made. On this reckoning $5,000\times600\times0.27=$ 810,000m., the difference, 12,240m., is imputable in part to that of the points of departure, in part to the error we, perhaps, make as to the length of the Egyptian foot in raising it to 0.27m. Thus, the measurement executed in Egypt more than 21 centuries ago, by an able Greek astronomer, is as good as authentic. All the causes of uncertainty do not alter it 1-60th; and it is certainly not from this quarter that the error of 1-6th, which we are seeking to account for, comes.

No more does it come from the measurement of Ptolemy, for he performed the same operations, and obtained the same result. Only, he gives 500 stadia to a degree, instead of 700. This difference evidently arises from the fact that Ptolemy, who lived four hundred years after Eratosthenes, under another rule, did not employ the same foot. In fact, he employed the stadium of 600 Phileterian feet, and as this foot is nearly 0.36m., while the ancient Egyptian foot was only 0.27m., it was necessary to reduce the 700 stadia of his predecessor to

$$700\times=\frac{27}{36}=525, \text{ or } 500 \text{ in round numbers.}$$

These appreciations are confirmed by the Arabian astronomers who measured in 827, an arc of 1° in the plains of Mesopotamia. They obtained 56 miles, and concluded that they had thus verified the number of Ptolemy. The Arabian mile was 2,100m.; the arc measured was found 117,600m., which answers to a stadium of 235m. This is pretty near the Phileterian stadium of 216m., allowing for the error of measurements, seven times more sensible on an axis so small, and the uncertainty of our present estimation of the Arabian mile in the time of the caliph Almamoun.

En résumé, the evaluation of Ptolemy is merely a sort of conversion of the excellent measure of Eratosthenes into units of another epoch, and different length. It must have lost, thus, a little of its first precision; but, as presented by Ptolemy, the English geographers had good reason to take it as base of an evaluation of the arc of one degree, and to offer it to nautical men of their country. Only, and here is the mistake, they believed that the great Greek astronomer of Alexandria used the Greek foot. This is one hundredth and a half more than the English foot. If the English geographers of the 16th century forced this evaluation but a little and carried it to 5 hundredths, they would have found 630 English feet to the stadium, which they believed to have 600 Greek feet, and these 630 feet, or these 210 yards, multiplied by 500, would have given them 105,000 yards for the degree, and exactly 1,760 yards for the mile.

The English mile, then, has probably been deduced from the measure of Ptolemy; its error of 1-6th is due simply to confounding the Greek foot with the Phileterian foot.

THE AMERICAN SOCIETY OF CIVIL ENGINEERS.

Address of the President, JAMES B. FRANCIS, before the Annual Convention at Montreal.

You have assembled in convention for the first time outside the limits of the United States, and I congratulate you on the selection of this beautiful city, in which and its immediate neighborhood there are so many interesting engineering works, constructed with the skill and solidity characteristic of the British school of engineering. Nine of our members are Canadian engineers, which must be the excuse of the other members for invading foreign territory.

The Society was organized Nov. 3, 1852, and actively maintained up to March 2, 1855. Eleven only of the present members date from this period. October 2, 1867, the Society was reorganized on a wider basis, and from that time to the present, it has been constantly increasing in interest and usefulness.

The membership of the Society is now as follows;

Honorary members	11
Corresponding members	3
Members	491
Associates	21
Juniors	57
Fellows	53
Total	636

During the last year we have lost six members by death and five by resignation, and fifty-six new members have been elected and qualified.

The most interesting event to the Society since the last convention, has been the purchase of a house in the City of New York, as a permanent home, at a cost of $30,000. This has been accomplished, so far, without taxing the resources of the Society, the required payments having been met by subscription. The sum of $11,900 had been subscribed to the building fund up to the 25th ultimo, by seventy members, and twenty-nine friends of the Society who are not members. The subscription is still open, and it is expected that large additions will be made to it by members and their friends, to enable the Society to make the remaining payments without embarrassment.

Meetings of the Society are held twice in each month, during ten months in the year, for the reading and discussion of papers and other purposes; the new house affords much better accommodations for these purposes than we have ever had before, and also for the library, which now contains 8,850 books and pamphlets, and is constantly increasing. A catalogue of the library is being prepared. Part I., embracing railroads and the transactions of scientific societies, has been printed and furnished to members.

WATER POWER.

Water power in many of the States is abundant, and contributes largely to their prosperity. Its proper development calls for the services of the civil engineer, and as it is the branch of the profession with which I am most familiar, I propose to offer a few remarks on the subject.

The earliest applications were to grist and saw mills; carding and fulling mills soon followed; these were essential to the comfort of the early settlers, who relied on home industries for shelter, food and clothing, but with the progress of the country came other requirements.

The earliest application of water power to general manufacturing purposes, appears to have been at Paterson, New Jersey, where "The Society for establishing Useful Manufactures" was formed in the year 1791. The Passaic river at this point furnishes, when at a minimum, about eleven hundred horse power continuously, night and day.

The water power at Lowell, Massachusetts, was begun to be improved for general manufacturing purposes in 1822. The Merrimack river, at this point, has a fall of thirty-five feet, and furnishes, at a minimum, about ten thousand horse power, during the usual working hours.

At Cohoes, in the State of New York, the Mohawk river has a fall of about one hundred and five feet, which was brought into use systematically very soon after that at Lowell, and could

furnish about fourteen thousand horse power, during the usual working hours; but the works are so arranged that part of the power is not available at present.

At Manchester, New Hampshire, the present works were commenced in 1835. The Merrimack river, at this point, has a fall of about fifty-two feet, and furnishes, at a minimum, about ten thousand horse power, during the usual working hours.

At Lawrence, Massachusetts, the Essex Company built a dam across the Merrimack river, commencing in 1845, and making a fall of about twenty-eight feet, and a minimum power, during the usual working hours, of about ten thousand horse power.

At Holyoke, Massachusetts, the Hadley Falls Company commenced their works about 1845, for developing the power of the Connecticut river at that point, where there is a fall of about fifty feet, and at a minimum, about seventeen thousand horse power, during the usual working hours.

At Lewiston, Maine, the fall in the Androscoggin river is about fifty feet; its systematic development was commenced about 1845, and with the improvement of the large natural reservoirs at the head waters of the river, now in progress, it is expected that a minimum power, during the usual working hours, of about eleven thousand horse power will be obtained.

At Birmingham, Connecticut, the Ousatonic Water Company have developed the water power of the Housatonic River, by a dam giving twenty-two feet fall, furnishing, at a minimum, about one thousand horse power, during the usual working hours.

The Dundee Water and Land Company, about 1858, developed the power of the Passaic river, at Passaic, New Jersey, where there is a fall of about twenty-two feet, giving a minimum power, during the usual working hours, of about nine hundred horse power.

The Turner's Falls Co. in 1866, commenced the development of the power of the Connecticut River at Turner's Falls, Massachusetts, by building a dam on the Middle Fall, which is about thirty-five feet, and furnishes a minimum power, during the usual working hours, of about ten thousand horse power.

I have named the above water powers as being developed in a systematic manner from their inception, and of which I have been able to obtain some data. In the usual process of developing a large water power a company is formed, who acquire the title to the property, embracing the land necessary for the site of the town to accommodate the population which is sure to gather around an improved water power. The dam and canals or races are constructed, and mill sites with accompanying rights to the use of the water are granted, usually by perpetual leases subject to annual rents. This method of developing water power is distinctly an American idea, and the only instance where it has been attempted abroad, that I know of, is at Bellegarde, in France, where there is a fall in the Rhone of about thirty-three feet. Within the last few years, works have been constructed for its development, furnishing a large amount of power, but from the great outlay incurred in acquiring the titles to the property, and other difficulties, it has not been a financial success.

The water powers I have named are but a small fraction of the whole amount existing in the United States and the adjoining Dominion of Canada. There is Niagara with its two or three millions of horse power; the St. Lawrence, with its succession of falls from Lake Ontario to Montreal; the Falls of St. Anthony, at Minneapolis, and many other falls, with large volumes of water, on the upper Mississippi and its branches. It would be a long story to name even the large water powers, and the smaller ones are almost innumerable. In the State of Maine a survey of the water power has recently been made, the result, as stated in the official report, being "between one and two millions of horse powers," part of which will probably not be available. There is an elevated region in the northern part of the South Atlantic States, exceeding in area one hundred thousand square miles, in which there is a vast amount of water power, and being near the cotton fields, with a fine climate, free from malaria, its only needs are railways, capital and population, to become a great manufacturing section.

The design and construction of the works for developing a large water

power, together with the necessary arrangements for utilizing it and providing for its subdivision among the parties entitled to it, according to their respective rights, afford an extensive field for civil engineers; and in view of the vast amount of it, yet undeveloped, but which with the increase of population and the constantly increasing demand for mechanical power, as a substitute for hand labor, must come into use, the field must continue to enlarge for a long time to come.

There are many cases in which the power of a waterfall can be made available by means of compressed air, more conveniently than by the ordinary motors. The fall may be too small to be utilized by the ordinary motors; the site where the power is wanted may be too distant from the waterfall, or it may be desired to distribute the power in small amounts at distant points.

*A method of compressing air by means of a fall of water has been devised by Mr. Joseph P. Frizell, C. E., of St. Paul, Minnesota, which from the extreme simplicity of the apparatus promises to find useful applications. The principle on which it operates is, by carrying the air in small bubbles in a current of water down a vertical shaft, to the depth giving the desired compression, then through a horizontal passage in which the bubbles rise into a reservoir near the top of this passage, the water passing on and rising in another vertical or inclined passage, at the top of which it is discharged—of course, at a lower level than it entered the first shaft.

The formation at waterfalls is usually rock, which would enable the passages and the reservoir for collecting the compressed air, to be formed by simple excavations, with no other apparatus than that required to charge the descending column of water with the bubbles of air, which can be done by throwing the water into violent commotion at its entrance, and a pipe and valve for the delivery of the air from the reservoir.

The transfer of power by electricity is one of the problems now engaging the attention of electricians, and it is now done in Europe in a small way. Sir William Thompson stated in evidence before an English Parliamentary committee, two years ago, that he looked "forward to the Falls of Niagara being extensively used for the production of light and mechanical power over a large area of North America," and that a copper wire half an inch in diameter would transmit twenty-one thousand horse power from Niagara to Montreal, Boston, New York or Philadelphia. His statements appear to have been based on theoretical considerations, but there is no longer any doubt as to the possibility of transferring power in this manner; its practicability for industrial purposes must be determined by trial. Dr. Paget Higgs, a distinguished English electrician, is now experimenting on it in the city of New York.

Great improvements in reaction water wheels have been made in the United States within the last forty years. In the year 1844 the late Uriah Atherton Boyden, a civil engineer of Massachusetts, commenced the design and construction of Fourneyron turbines, in which he introduced various improvements and a general perfection of form and workmanship, which enabled a larger percentage of the theoretical power of the water to be utilized than had been previously attained. The great results obtained by Boyden with water wheels made in his perfect manner, and in some instances almost regardless of cost, undoubtedly stimulated others to attempt to approximate to these results at less cost, and there are now many forms of wheel of low cost, giving fully double the power, with the same consumption of water, that was obtained from most of the older forms of wheels of the same class.

ANCHOR ICE.

A frequent inconvenience in the use of water power in cold climates is that peculiar form of ice called anchor, or ground ice. It adheres to stones, gravel, wood and other substances forming the beds of streams, the channels of conduits and orifices through which water is drawn; sometimes raising the level of water courses many feet by its accumulation on the bed, and entirely closing small orifices through which water is drawn for industrial purposes. I have been for many years in a position to observe its effects, and the conditions under which it is formed.

*Journal of the Franklin Institute for Sept. 1877.

The essential conditions are, that the temperature of the water is at its freezing point, and that of the air below that point; the surface of the water must be exposed to the air, and there must be a current in the water.

The ice is formed in small needles on the surface, which would remain there and form a sheet if the surface was not too much agitated, except for a current or movement in the body of water sufficient to maintain it in a constant state of intermixture. Even when flowing in a regular channel there is a continued interchange of position of the different parts of a stream; the retardation of the bed causes variations in the velocity which produces whirls and eddies, and a general instability in the movement of the water in different parts of the section. The result being that the water at the bottom soon finds its way to the surface, and the reverse. I found by experiments on straight canals in earth and masonry, that colored water discharged at the bottom reached the surface at distances varying from ten to thirty times the depth.* In natural water courses, in which the beds are always more or less irregular, the disturbance would be much greater. The result is that the water at the surface of a running stream does not remain there, and when it leaves the surface it carries with it the needles of ice, the specific gravity of which differs but little from that of the water, which, combined with their small size, allows them to be carried by the currents of water in any direction. The converse effect takes place in muddy streams. The mud is apparently held in suspension, but is only prevented from subsiding by the constant intermixture of the different parts of the stream; when the current ceases the mud sinks to the bottom, the earthy particles composing it, being heavier than water, would sink in still water in times inversely proportional to their size and specific gravity. This, I think, is a satisfactory explanation of the manner in which the ice formed at the surface finds its way to the bottom; its adherence to the bottom, I think, is explained by the phenomenon of *re-gelation*, first observed by Faraday; he found that when the wetted surfaces of two pieces of ice were pressed together they froze together, and that this took place under water even when above the freezing point. Professor James D. Forbes found that the same thing occurred by mere contact without pressure, and that ice would become attached to other substances in a similar manner. Re-gelation was observed by these philosophers in carefully arranged experiments with prepared surfaces, fitting together accurately, and kept in contact sufficiently long to allow the freezing together to take place. In nature these favorable conditions would seldom occur in the masses of ice commonly observed, but we must admit, on the evidence of the recorded experiments, that, under particular circumstances, pieces of ice will freeze together, or adhere to other substances, in situations where there can be no abstraction of heat.

When a piece of ice of considerable size comes in contact under water with ice or other substance, it would usually touch in an area very small in proportion to its mass, and other forces acting upon it, and tending to move it, would usually exceed the freezing force, and re-gelation would not take place. In the minute needles formed at the surface of the water the tendency to adhere would be much the same as in larger masses touching at points only, while the external forces acting upon them would be extremely small in proportion, and re-gelation would often occur, and of the immense number of the needles of ice formed at the surface, enough would adhere to produce the effect which we observe and call anchor ice. The adherence of the ice to the bed of the stream or other objects is always downstream from the place where they are formed; in large streams it is frequently many miles below; a large part of them do not become fixed, but as they come in contact with each other, re-gelate and form spongy masses, often of considerable size, which drift along with the current, and are often troublesome impediments to the use of water power.

Water powers supplied directly from ponds or rivers or canals frozen over for a long distance, immediately above the places from which the water is drawn, are not usually troubled with anchor ice, which, as I have stated, requires open water, upstream, for its formation.

* Paper CLX. in the Transactions of the Society, 1878. Vol. VII., pages 109, 168.

THE CORROSION OF IRON AND MILD STEEL.

From "The Engineer."

THE minds of those interested in the extended use of mild steel for constructive purposes have lately been somewhat troubled. Mr. Philips, secretary to the late Admiralty Boiler Committee, read a paper a few weeks since before the Institution of Civil Engineers, setting forth the results of certain experiments made by that committee, together with certain others since made by himself. The conclusions deducible from these experiments were that mild steel under almost all conditions to which it is likely in practice to be exposed, corrodes much faster than wrought iron. If this be really the case it naturally follows that mild steel is a much less trustworthy material than it was supposed to be; and the reduction of weight of scantlings now allowed by Lloyd's surveyors, in consideration of superior tensile strength, ought to be in future prohibited, while the reduction in thickness in steel plates for marine boilers, as compared with iron, must also be discontinued. For it is not so much the strength of a structure when brand new that needs consideration, as its strength after a few years of active or passive service. If corrosion should be proved to be likely to do its deadly work upon steel considerably more rapidly and completely than upon iron, how can original reductions of thickness be any longer safely permitted when the more corrodible material is used? It is true that some rather severe criticisms were passed on Mr. Philips' paper during its discussion, but inasmuch as the Institution of Civil Engineers' meetings are not open to the public, nor attended otherwise than occasionally by members of the iron and steel trades, the unfavorable effect of the paper as regards mild steel might be considered still to remain in full force. In this position of affairs Mr. Parker's paper upon the same subject was placed first on the list at the recent meeting, in London, of the Iron and Steel Institute, and was generally pronounced to be extremely opportune. There is scarcely any one whose evidence on such a matter is entitled to more respect, whether on account of the writer's great practical experience, his thorough technical knowledge, his independent position, or his fearless candor, as testified by his recent paper on the "Livadia's" boilers. Mr. Parker was therefore expected to give valuable and trustworthy evidence, and so he did. Let us now consider what he said.

He first reviewed the experiments made by the Admiralty Boiler Committee, admitting that on the surface they appeared decidedly unfavorable to steel. He considered, however, that the deductions made from them were open to question, because in making the tests due care had not been taken to prevent galvanic action. He did not refer to the tests which Mr. Philips had subsequently made privately and on his own responsibility. Why this omission was made has yet to be explained. He next reviewed the experiments made more than forty years ago by Mr. Robert Mallet, and though he recognised some value in them, he considered that they also, on account of their want of completeness, are unavailing in settling the present question. He then carefully described his own experiments, made by exposing six bright and six black discs to six varieties of corroding conditions, obtained from each of two makers of common iron, four of high-class iron and four of mild steel plates. The discs were in all cases 4½ in. diameter by ¼ in. thick. By means of glass insulators, and by carefully excluding other metals from the test groups, he endeavored to avoid galvanic action. He first gave the results obtained from the six groups of bright specimens, and afterwards from those which had been exposed to the black or unscaled condition, In the case of the bright specimens the loss by corrosion is given in pounds per square foot per annum. For the sake of simplicity we have further condensed the results to one average for cold and one for hot corrosion. The former includes exposing to the action of cold sea water, bilge water and the London atmosphere; the latter includes three experiments in the water spaces of sea-going boilers under slightly

different circumstances. The mean result in pounds per square foot per annum is as follows: Cold—Common iron, .267; best Yorkshire iron, .294; mild steel, .318. Hot—Common iron, .261; best Yorkshire iron, .298; mild steel, .376. In other words, the excess of liability to corrode over and above common iron plates is as follows: Cold—Best Yorksire, 10 per cent.; mild steel, 19 per cent. Hot—Best Yorkshire, 14 per cent., mild steel, 44 per cent.

The common iron comprised specimens of Cleveland and of Glasgow plates; the best Yorkshire of Leeds, Bowling, Farnley and Lowmoor; and the mild steel of Landore, Sheffield, Bolton and the Steel Company of Scotland's make. Leaving these startling results of the experiments with the bright discs for a moment, let us proceed to the consideration of those with the black discs. Here Mr. Parker does not give us the loss in pounds per square foot per annum, but having in his mind the fact that a plate perforated by pitting is as much spoilt as one rusted away equally over its surface, he confines himself to determining the average depth of corrosion locally, where accidentally denuded of scale, of black plates compared with the same generally of bright plates. He finds a great increase of irregularity resulting from carelessness in leaving the scale on. Thus, with the bright specimens, the ratio 80: 100 about expresses the maximum variation in the loss between any two specimens similarly tested, whether common or best Yorkshire iron, or mild steel. But with the black specimens, whilst 40: 100 expresses the variation for common iron, 30: 100 expresses that for best Yorkshire iron, and 20: 100 for mild steel. The fickleness of unscaled mild steel as to corrosion is apparently much greater than that of best Yorkshire iron, and double that of common iron. The general conclusion drawn by Mr. Parker from the experiments with the black specimens is, that leaving the scale on induces pitting, which is tantamount to more rapid destruction of the plates. Although scale may be, and no doubt is, a protection to the part it covers, it evidently contributes to the more rapid destruction of the neighboring parts; and, therefore, unless it be complete and enduring, as it may some day be made by the "Bower Barff" process, it is worse than useless. Mr. Parker advocates—and in this we fully agree with him—that in the meantime all scale should carefully be removed, leaving the bare metallic plate to ordinary oxidizing influences, in case of the removal of paint, or of such other covering as may be artificially given to it when the structure is new. Dismissing for this reason further consideration of unscaled plates, we have only to deal with those which have been scaled, and which are, therefore, correctly represented by the bright specimens. Indeed, as soon as the first film of rust pervades a bright plate, it is in exactly the same condition as a new plate from which the scale had been carefully removed. The question we have placed before us is, how is mild steel likely to stand corrosion in ships and in boilers, as compared with the iron of which these structures have hitherto been mostly made? Here, we regret to say, we find ourselves somewhat at variance from Mr. Parker. We accept, or rather we do not dispute his facts; but his conclusion seems to us unwarranted, and to some extent misleading. Perhaps we ought rather to say that the general impression conveyed by his own summing up of his paper is not, in our opinion, justified by his experiments. It is almost impossible at one sitting to grasp the full bearings of a technical paper, such as this, containing a number of statistical figures; and an audience naturally looks for guidance to the writer as to the conclusions they may properly draw. It is these conclusions which we, after a careful re-perusal, are disposed to find fault with. The following are extracts from Mr. Parker's paper, containing the conclusions referred to: "Although the average loss of steel is a little greater than of iron, the difference is so slight that for practical purposes it is safe to assume that bright steel, exposed to sea or bilge water, corrodes no faster than bright iron, especially than the better qualities of iron." "When exposed to the atmosphere, although there is no great difference between the common and the better sorts of iron, the steel appears to have lost considerably more than either Lowmoor or any other iron, and the same is the case with those discs exposed to the action of boiling water with or without zinc. Again, in another place: "So that

although the present experiments confirm the prevailing impression that bright mild steel does corrode faster than iron, when we get from cold sea water to the condition of a marine boiler the difference is not so great as to establish the matter beyond question." And further on: "It would perhaps not be far wrong, speaking generally, to say that the different pieces of iron differed as much among themselves as they did from steel; and certainly the effect produced on my mind after carefully weighing the results of the experiments has not been to raise any apprehension that steel boilers or steel ships are likely in the future to corrode to any serious extent more rapidly than iron." As to the practical working of the 1,100 steel boilers now in use: "Greater irregularity in the corrosion of the steel is reported, due to the unequal action of the scale; and, finally: "Neither from the series of experiments which I have described, nor from our daily experience up to the present time, is there any reason to believe that the question of corrosion is likely to form a bar to the extended use of steel for marine boiler-making purposes."

Now, when we consider that no ship afloat has been built of "Lowmoor" or any other prime brands of "best Yorkshire iron," or is any ever likely to be on account of the cost, there is no use introducing into the discussion the liability of such brands to corrosion as compared with steel in ship construction. Having successfully driven iron nearly out of the market for rails, steel makers are now naturally endeavoring to do the same as regards ship-building material. But it is the so-called common irons of Cleveland and Glasgow that have to be superseded, if any, and not those of Lowmoor or the Leeds district. In ships the corroding elements to be contended with are three, every part of the hull being liable to be acted on by one or other of these. They are cold sea water, bilge water and the atmosphere. The practical aim of the manufacture must therefore be, to make iron or steel which will stand any one of these destructive agencies—and no one can say to which one a particular plate will be most subjected. We therefore have amalgamated Mr. Parker's first three columns of results into one general result for "cold corroding," which nearly corresponds with ship-plate corrosion. This we have shown drives us to the startling conclusion that mild steel corrodes 19 per cent. faster than the iron ship plates at present in use. In other words, by the time a clean, unpainted Cleveland ship plate $\frac{5}{8}$ in. thick has corroded away, a $\frac{3}{4}$ in. mild steel plate would also be completely oxidized; and yet, the steel ships now under construction and afloat are not 20 per cent. thicker—as it would appear they ought to be—but 20 per cent. thinner than they would have been of iron.

As to boilers, the fact brought out by Mr. Parker that mild steel in boiler water spaces corrodes 44 per cent., and best Yorkshire iron 14 per cent. quicker than common iron, is startling in the extreme. Indeed, had Mr. Philips been present at the discussion—and it is a matter of regret that he was not—he would have been justified in making some rather pertinent and forcible observations. He might have said very properly: "It is contended that the Boiler Committee's experiments are valueless, and by inference that my whole paper, which included other confirmatory experiments, should be discredited; and yet this new set of experiments, in the making of which all previous faults have been avoided, has produced very similar results. I claim that the position I took has been strengthened, and not weakened." It must not be supposed that common iron is out of court in consideration of this part of the question. Common iron, as here understood, is the iron of the Cleveland and Glasgow districts. Large quantities of boiler plates are made in both these districts for marine and other purposes; and these are more carefully made than ship plates, yet they are mainly from the native pig irons; and as far as resistance to corrosion goes, there is no doubt they have all the good qualities of the lower brands. It is probable that the weight of iron from the whole best Yorkshire district worked up annually into marine boilers is quite insignificant compared to what at present is being supplied by Glasgow and the North of England. Indeed, mild steel has for long been so much cheaper in comparison that the question for consideration has been: "Shall it be Cleveland or Scotch iron boiler plate, or shall it be mild steel?"

And not, "Shall it be mild steel or best Yorkshire iron?" The very high initial cost and the heavy extras rigidly enforced, amounting in many cases to £50 to £60 per ton, have precluded the use of Yorkshire iron except, as it were, as a luxury. Much more might be said, if space permitted, about the physical properties of iron and steel. Professor Kennedy's paper, recently read before the Institution of Mechanical Engineers, and the discussion thereon, disclosed some remarkable facts, hitherto unknown or unappreciated. Among these we may mention: (1) That permanent set commences with mild steel—which alone is admissible for ships or boilers—at about 8 tons per square inch, as compared with 11 or 12 tons with North country iron; (2) that at about 18 tons per square inch a distinctive "breaking down" or disintegration takes place, which has no analogy in iron short of its final breaking strain of, say, 21 tons per square inch; and (3) that for thicknesses above $\frac{3}{4}$ in. or $\frac{7}{8}$ in. mild steel is no stronger, and on account of the impossibility of doing sufficient work upon it, less trustworthy than iron. But our present object has been to discuss Mr. Parker's valuable paper upon corrosion, and therefore we content ourselves with simply alluding to the physical peculiarities of steel just named. In, conclusion, we would ask shipowers shipbuilders, ship insurers and underwriters' surveyors to pause for a moment and ponder deeply, whether, metaphorically speaking, it is not possible there may be "rocks ahead" which will, in a not very distant future, play havoc with structures made of extra thin plates of extra corrodible material.

On the Work of a Man for Short Periods.—By Dr. Hartig.—At the fire brigade congress at Dresden in June, 1880, dynamometrical observations were made of the power required to work the different hand fire-engines exhibited. Amongst other results these experiments give an insight into the amount of work which can be performed by men working for very short periods at a lever.

The engines were placed in the open air, under a hot sun; they were worked by infantrymen, and each squad worked for two minutes only at a time. The following are selected from the table of seventeen experiments given in the paper:

Number of experiment	i	viii.	ix.	xi.	xvii.	mean of 17.
Mean height of lever above ground.... inches	40.25	38.7	38.54	49.31	38.38	..
Length of lever..... "	49.2	46.7	43.5	70.5	58.7	..
Stroke..... "	38.8	35.0	35.9	45.5	37.4	..
Number of double strokes per minute...	48	55	49	55	60	..
Mean velocity of handle....feet per sec.	5.17	5.33	4.9	6.95	6.23	5.78
Horse power exerted per man.....	0.324	0.227	0.403	0.306	0.395	0.297

Morin and Weisbach give 5.5 meter-kilogrammes per second = 2,387 foot-lbs. per minute as the work that a man can do for eight hours together; the above mean work is greater than this in the ratio $\frac{0.297 \times 33000}{2387} = 4.1$ nearly.

—*Der Civilingenieur.*

Different Varieties of Steel.—The following correct definitions of the different varieties of steel by William Metcalf, of the Crescent Steel Works, Pittsburgh, Pa., are published in a circular by the Dexter Spring Company, of Hulton, Pa.

Originally the word steel was applied only to iron which contained such quantities of carbon as would cause hardening when the red-hot iron was cooled suddenly.

This definition still applies, but, in addition, the term cast steel applies to all of the products of the crucible, the Bessemer converter, and the open-hearh furnace, whether such products are too low in carbon to harden or not. The steels that are not cast steel are known in the market as blister steel, German steel, shear steel, and double shear steel.

Blister steel is made by heating bars of wrought iron, bedded in charcoal, in hermetically sealed chambers. The carbon of the charcoal penetrates the hot

iron, converting it into a crystalline mass of crude steel; large blisters rise on the surfaces of the bars, giving the name blister steel to this product.

German steel is blister steel rolled down into bars. It is used mainly for tires and common springs, but is being rapidly superseded by the cheaper grades of cast steel.

Shear steel is made by taking a high heat on blister steel and hammering it thoroughly. Double shear steel is made by cutting up shear steel, piling it, heating it, then hammering again. The best shear steel must be made from the best wrought iron. The shear steels are very useful on account of their toughness and the ease with which they can be welded to iron, and, when of good quality and well worked, they will hold a very fine edge.

Crucible steel is made by melting in a crucible either blister steel, or blister steel and wrought iron, or wrought iron and charcoal, or wrought iron and scrap steel, or, in short, a great variety of mixtures, which depend on the quality of steel to be produced.

Crucible steel can be applied to any purpose for which steel is used. Generally, it is better than any other steel—that is to say, crucible steel made by melting blister steel and tempered to suit by mixing iron of the same grade in the crucible is always better than German or shear steel made from the same blister.

Bessemer steel is made by blowing air through melted cast iron, thus burning silicon and carbon out of the cast iron. After the silicon and carbon are burned out melted spiegeleisen or ferro-manganese is added to the charge. The carbon in the spiegel re-carbonizes the steel to the desired point, and the manganese unites with and removes the oxygen which the air used leaves in the steel.

Open-hearth steel is made by melting, in a very hot furnace, a charge of pig iron. To this melted iron, which is called the "bath." is added either wrought iron, or scrap steel, or iron ore, and the whole is kept hot until all is melted. The wrought iron, or scrap, or ore reduces the carbon and silicon in the bath to such proportions as are desired in the steel.

Bessemer and open-hearth steel are much alike in quality. They are used mainly for rails, boiler plates, ship plates, bridge and other structural purposes, and machinery. The better qualities are also used largely for springs. The best spring steel, like the best tool steel, is simply that which is made from the best material. Quality of material, chemically speaking, being equal, the best spring steel is that which is made from crucible cast steel, as the crucible process is less crude than either of the others.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—The Society held their thirteenth annual Convention at Montreal, Canada, June 15th. In addition to the discussions upon the papers of the past year, the following papers were presented to the Convention:

Re-enforcement of the Anchorage and Renewal of the Suspended Structure of the Niagara Railroad Suspension Bridge: L. L. Buck.

The Stability of Tunnels in River Silt: Ashbel Welch.

Repairs of Masonry: O. Chanute.

Experiments upon Strength of Wrought Iron Columns: T. C. Clarke.

On Weights and Measures: Charles Latimer.

Comparative Economy of Light and Heavy Rails: Ashbel Welch.

ENGINEERS CLUB OF PHILADELPHIA.—Record of Meeting, May 21st.—A paper on the Comparative Anatomy of Locomotive Engines was read by Mr. Geo. Burnham, Jr.

Prof. Haupt replied to Dr. Chance's comments on the benefit to be derived from diagonal thoroughfares.

Dr. Chance concludes, that whilst diagonals "would pay, financially," and should be introduced into every proposed plan of a city, yet they would increase the density and hence be objectionable. To this Prof. Haupt answers that additional avenues, to a limited extent, would open new air channels, admit more sunlight into the dwellings, would not practically increase the density of population, would concentrate business,—enabling it to be attended to with much less loss of time and trouble,—and would practically extend the radius of the city to an extent equal to the distance saved, thus enabling the populace to go that much farther into the suburbs without increase of time or expense.

In brief, both from a sanitary point of view and financially, the proposed system would be a gain to the private citizen, to the business man, to the property owner and to the city, and the original estimate of benefits to be conferred, instead of being excessive, are believed to be far below the actual results which would follow the introduction of such a system

Mr. Rudolph Hering exhibited and explained a number of ancient and modern maps of Eu-

ropean and Asiatic cities, showing the method of their development.

Mr. Chas. A. Ashburner, of the State Geological Survey, has adopted the Amsler's Planimeter for the estimation of the mine areas in the survey of the Anthracite Coal Fields of Penna. He has subjected the accuracy of the instrument to a severe test. In computing areas in square inches of map surface, it was found that the maximum error was one-quarter of one per cent. In computing areas on maps of large scale the average error of the planimeter is believed to be less than either the minimum error of a careful compass survey or of an accurate plot.

June 4th.—Prof. L. M. Haupt read some notes on Cobble Stone Pavements, commenting on the great variety of size and form, as exhibited in the streets of this city. He gave extracts from the Ordinance of June 12th, 1868, specifying the size of such stones to be not more than "9 or less than 6 inches in depth, or showing a greater length of face than 7 or less than 4 inches"—and then stated the characteristics of one "cobble" which he took up, weighed and returned to its position. It was found to be 38 inches long by 25 wide by 10 deep;—to contain 4 cubic feet and to weigh 625 pounds, or one hundred times the weight and volume of the average stone as specified.

The form of cobble stones, being spheroidal, was also shown to be unfavorable to resist the forces which act upon them, and the practical absence of friction between the surfaces of contact render them unstable and entirely unfit to perform the duties required of a good pavement.

The porosity of such a surface covering, admitting water freely to the substructure of gravel, loam and clay, which expands forcibly in Winter, raising the entire surface, and shrinks away under the influence of the spring temperature, leaving the stones unsupported, was mentioned as another element of destruction and expense; and altogether it was concluded that the cobble stones were unstable, unsafe, unclean and ultimately more expensive than well laid Belgian blocks having concrete foundations.

Prof. Haupt also read a brief discussion on the methods of expressing the scales of maps and of determining their relations to each other, so as to avoid ambiguity, giving a sample formula applicable to any case.

Mr. Frederic Graff exhibited an ancient map of Philadelphia, made to show the location of the early hose companies of the city.

THE NEW YORK ELECTRICAL SOCIETY.—The New York Electrical Society was organized March 2d, 1881, for the advancement and spreading of Electrical knowledge.

These objects will be attained by the holding of periodical meetings, and the founding of a reading room, library and laboratory.

The Society meets on the first and third Thursdays of each month in the Chemical Lecture Room of the Cooper Union.

The following are the officers:

President, F. W. Jones; Vice-Presidents, Geo. B. Scott, P. H. Van der Weyde, Gerritt Smith, W. J. Dealy, Geo. A. Hamilton, Geo. G. Ward; Secretary, J. W. Moreland; Treasurer, M. Brick; Executive Committee, F. W. Jones, Geo. B. Scott, J. W. Moreland, G. L. Wiley, E. C. Cockey, C. S. H. Small.

There are 240 members.

ENGINEERING NOTES.

MEASURING ELECTROMOTIVE FORCE.—A new method of measuring the electromotive force of a battery by means of the torsion balance has been applied successfully by M. J. B. Baille, and the results communicated to the French Academy. To obtain good indications the perturbations due to the trembling of the ground and the electricity of the atmosphere had to be eliminated by mounting the instrument on solid pillars, and enclosing it in a metal case connected to the earth. Variations of temperature are also guarded against by a thick jacket of wood shavings around the balance. The balance employed consisted of a long torsion wire of annealed silver, carrying at its lower end a lever terminated by two gilded copper balls. The lever was suspended at an equal distance from four similar fixed balls placed at the corners of a rectangle, each diagonal pair of balls being connected by wire. The lever was connected by the torsion wire to the positive pole of a standard battery, the other pole being to earth. One pole of the battery to be measured was then connected to the fixed balls, the other pole being to earth, and the deflections of the lever observed on a scale of clear glass placed about 10 ft. from the lever. Coulomb's well-known formula for static charges gave the electromotive forces of the cells measured. The following numbers represent the potential of an element of the kind described, that is the quantity of electricity spread upon a sphere of 1 centimeter radius, in electric units.

	Open circuit.
Voltaic cell	0.03415
Zinc, sulphate of copper, copper cell...	0.02997
Zinc, acidulated water, sulphate of copper	0.03709
Zinc, salt water, carbon, peroxide of manganese...	0.05282
Zinc, salt water, platinum, chloride of platinum...	0.05027
Zinc, acidulated water, carbon, nitric acid	0.06285

IN a pamphlet on the London water supply, and speaking of well water from the chalk, Mr. J. Lucas, F. G. S., says:—It would be utterly rash to count upon more than an average of 6 in. of rain passing into the underground water systems. Then if a mean quantity of 6 in. be supplied annually to the chalk, and it were in contemplation to inquire whether the whole water supply of London could be supplied from the chalk of the Thames basin, the question would be answered in this way—It would, at this rate, take the whole supply of 588.232 square miles to furnish 140,000,000

gallons per day—if it were po-sible to obtain the whole. Assuming, before making a proper survey, that only one-third could be taken, then an area of 1767 square miles would be required to furnish the same quantity, but the Thames basin, as far east as the western boundary of the Medway basin, and exclusive of the Lea, contains only 1265 square miles of chalk. The Lea basin contains about 250 square miles of chalk, which brings up the total to about 1500 square miles of chalk in the Thames basin; therefore, if after a close survey these figures could be substantiated, the chalk of the Thames basin could not supply the whole requirements of the metropolis for all purposes, but if the whole area of 1500 square miles were brought under contribution so as to yield one third of its total supply, it would in that event fall short of the present total requirements of the metropolis.

THE FINANCIAL ASPECT OF THE CHANNEL TUNNEL PROJECT.—Precedents as to cost would hardly justify an engineer in estimating a tunnel under the channel at less than £200 per yard, or £352,000 per mile—being less than half the cost of the metropolitan lines, of the cost of which, however, we must remember that the price of land formed an important, though undistinguished portion. To pay 5 per cent. on £350,000 per mile requires a traffic of about £35,000 per mile per annum, or more than five times as much as the South-Eastern Railway. No English railway approaches the quarter of this figure with the exception of the two metropolitan lines, which take respectively £38,600 and £34,300 per mile. These, it is well known, are entirely exceptional cases, fed by constant local urban traffic, with stations little more than half-a-mile apart. In the Channel tunnel there can be no local traffic Generally speaking, it will be only the through passengers from London to Paris, and *vice versa*, who could be depended on to feed the line. Taking all things in the most favorable light, we have to consider whether a traffic equal to that of the Metropolitan District line is rationally to be expected, under any circumstances, to arise between Dover and Calais.—*Builder.*

FAURE'S ACCUMULATOR—Among the important advances in electrical engineering may probably be reckoned the new *Accumulator* of M. Faure, although the performance of the apparatus thus far seems hardly to justify the enthusiastic predictions of some of the French journals.

The accumulator is an improvement upon, although a slight modification of, Plante's Secondary Battery. Lead plates covered with minium form the electrodes of the accumulator, and these are immersed in water acidulated with sulphuric acid. When an electric current is passed through the apparatus, the minium is brought to the condition of peroxide on the positive electrode, and reduced to metal on the negative. It is charged as a *quantity* and discharged as an *intensity* battery. It may be transported long distances after charging, and allowed to remain unused for considerable periods without serious loss of charge.

A Faure Accumulator, weighing seventy-five kilograms (165 lbs), it is claimed will perform the work of one horse power for one hour. It is proposed to apply it at once to electric lighting.

IRON AND STEEL NOTES.

DEPHOSPHORIZATION IN FRANCE. — Mr. Francis Saur writes: "The Thomas Gilchrist process is not very successful in the east of France, and its application has met with serious difficulties. The largest concern in that region is actually in a very bad way. There the dephosphorization is direct. Sometimes 500 tons of good products are manufactured (a little too soft, by the way). Then, suddenly, the working goes wrong. Some castings stay in the ladle, others in the converter. This information, coupled with the recent trials of dephosphorized rails made at Creusot, throws a peculiar light upon the matter. In the East, as at Creusot, manganese appears to be the remedy; but, then, where is the economy of the process? The question moves always in the same circle."

PRODUCTION OF THE IRON AND STEEL WORKS OF THE UNITED STATES.—The total production of the iron and steel works of the United States in the census year 1880, was 7,265,140 tons; in 1870 it was 3,655,215 tons; increase, 3,609,925 tons, or 98.76 per cent. The following table shows the production of each branch of our iron and steel industries in 1870 and 1880, with the percentage of increase or decrease in the latter year.

Iron and Steel Products.	Census year 1870. Net tons.	Census year 1880. Net tons.	Percentage of increase in 1880.	Percentage of decrease in 1880.
Pig iron and castings from furnace	2,052,821	3,781,021	84	—
All products of iron rolling mills	1,441,829	2,353,248	63	—
Bessemer steel finished products	19,403	889,896	4,486	—
Open-hearth steel finished products	—	93,143	—	—
Crucible steel finished products	28,069	70,319	151	—
Blister and other steel	2,285	4,956	117	—
Products of forges and bloomaries	110,808	72,557	—	35
Total	3,655,215	7,265,140	99	—

Of the pig iron and furnace castings produced in the census year 1880, there were produced with cold-blast charcoal, 79,613 tons; with hot-blast charcoal, 355,405 tons; with anthracite, 1,112.735 tons; with bituminous coal and coke, 1,515,107 tons; and with mixed anthracite and coke, 713,932 tons The furnace castings amounted to 4,229 tons. The total production was 3,781,021 tons, of which 12,875 tons were spiegeleisen.

GEOGRAPHICAL DISTRIBUTION OF THE IRON AND STEEL INDUSTRIES OF THE UNITED STATES.—The whole territory of the United States may be regarded as comprising four

grand divisions—the Eastern States, the Southern States, the Western States and Territories, and the Pacific States and Territories. Assuming that the Eastern States comprise all of the States lying north of Delaware and east of Ohio, that the Southern States comprise all of the late slaveholding States except Missouri, and that the other divisions require no explanation, we present the following comparative statement of the development of the iron and steel industries in each of the grand divisions in the census year 1880.

Grand Divisions.	No. of establishments.	Capital invested.	Hands employed.	Wages paid.	Net tons produced.	Value of all products.
Eastern States	556	$149,507,461	82,842	$34,301,660	4,671,808	$192,696,010
Southern States	218	29,145,880	20,595	6,361,344	649,133	25,353,251
Western States and Territories	224	50,755,900	36,603	14,542,987	1,912,689	76,393,696
Pacific States and Territories	7	1,562,603	878	311,194	31,490	1,574,738
Total United States	1,005	$230,971,884	140,978	$55,476,785	7,905,140	$296,557,085

In 1870 there were 25 States engaged in the manufacture of iron and steel. Of these, South Carolina does not appear in the statistics for 1880. Its total production in 1870 did not aggregate 500 tons. The iron industry in this State has been practically abandoned. Since 1870 three States have for the first time engaged in the manufacture of iron, namely, Colorado, Kansas, and Nebraska; also two territories, namely, Utah and Wyoming. Utah did not, however, make any iron in 1880. It made a small quantity in each of the years 1874, 1875, and 1876, and it will make a larger quantity in the near future. California and Washington Territory have made arrangements since the close of the census year 1880 to manufacture iron. New Hampshire made iron many years ago, but it does not appear in the statistics for 1870; it reappears in the tables for 1880. Oregon and Texas each built a blast furnace in the decade preceding the census year 1870, but they did not make any iron in that year; they appear, however, in the statistics of production for 1880. The District of Columbia once had a blast furnace in operation, but in 1870 it had no iron industry whatever; in 1880 the United States Government owned and operated a small rolling mill at the Washington Navy Yard. Minnesota appears in 1880 for the first time among iron-manufacturing States, but its statistics relate only to the preparations that have been made to embark in the business. Thirty States, the District of Columbia, and Wyoming Territory actually made iron in 1880.

PRODUCTION OF ALL THE STATES IN 1880.

States.	Production, 1880.	Rank.	States.	Production, 1880.	Rank.
Pennsylvania	3,616,668	1	Delaware	33,918	19
Ohio	930,141	2	Kansas	19,055	20
New York	598,300	3	California	14,000	21
Illinois	417,967	4	Maine	10,866	22
New Jersey	243,860	5	Territory of Wyoming	9,790	23
Wisconsin	178,935	6	Rhode Island	8,134	24
West Virginia	147,487	7	New Hampshire	7,978	25
Michigan	142,716	8	Vermont	6,620	26
Massachusetts	141,321	9	Colorado	4,500	27
Missouri	125,758	10	Oregon	3,200	28
Kentucky	123,751	11	Nebraska	2,000	29
Maryland	110,934	12	Texas	1,400	30
Indiana	96,117	13	North Carolina	439	31
Tennessee	77,100	14	District of Columbia	264	32
Alabama	62,986	15	South Carolina	—	—
Virginia	55,722	16			
Connecticut	38,061	17			
Georgia	35,152	18			

RAILWAY NOTES.

A most important railway item, particulars of which have never been collected for any line in the United Kingdom, is—Mr. Green remarks, in a recent paper on light railways, read before the Institution of Civil Engineers, Ireland—the number of passengers per carriage mile. On the French lines it averages 9.24, varying with the classes; the weight of carriages per seat is 517 lbs., but the real weight of carriages per passenger, allowing for empty seats, is 1632 lbs., or 1881 lbs., dividing the weight of the brake van among the passengers. The weight of vehicle, reduced in construction to double the weight per passenger, is exaggerated in practice to eight or ten times the same weight. To obtain the gross dead weight it is necessary to also add a proper proportion of the weight of the engine and tender; and taking into account trains with two engines, empty running, and bank engines, it is found that the engine mileage exceeds the passenger-train mileage from 3 to 5 per cent. Unfortunately, the passenger trains cannot be separated from mixed trains carrying high-speed goods—*i. e.*, luggage, carriages, horses, &c.—but in such cases apportioning the weight of engine and tender—assumed to be two-thirds full on an average—between the passengers and high-speed goods, the total dead weight is 17 and 10½ times the paying load respectively, while on the new systems the result is more unfavorable, the numbers being 22 and 14 respectively. On one of the Spanish railways, for each ton of passengers, the weight of vehicles run was 9.18 tons, or 18.98 including the engine.

In reference to the relative value of steel rails and iron rails, the following remarks of the chairman at the shareholders' meeting of

the North-Western Railway on Saturday are worth reproducing:—"They had nearly completed the whole of the work of relaying the road with steel rails both on the main line and branches, and they were deriving very great benefit this half-year from the economy which the introduction of the steel rail had produced. Going back to 1874, he found that the cost of relaying the line was £454,000 for materials alone, while in 1880 the total cost of relaying the line had been only £176,000. No doubt a very considerable portion of this difference was owing to the change in the cost of rails. Formerly the cost was much larger, but the average cost in the past half-year was £4 18*s.* 6*d.* per ton. When, however, they came to compare the number of miles relaid, he found that about 1875 and so forward they laid from 211 to 220 miles each year, whereas last year they had only needed to relay 150 miles. The question was, How long would that continue? He believed he told them once before that this year and last year were somewhere about an average of the future, but they did not feel very clear on that point, and they required a little more experience on the matter. He once told them that they put down some rails which weighed 84 lbs. to the yard, and they took them up at the end of sixteen years, when they weighed 59 lbs., but since then they had taken up some which weighed only 51 lbs. They never had any iron rails which wore away to a lower point than 74 lbs., so that, although the steel rails were lasting longer, they were wearing a certain quantity away each year; and they had therefore considered it prudent not to bring into division in the revenue the profit they made on the old rails a year ago."

ORDNANCE AND NAVAL.

THE NAVY IN 1881.—The Naval Estimates for the coming financial year were announced in the House of Commons on March 18th, by Mr. Trevelyan, the Secretary to the Admiralty. It is greatly to be hoped that when the separate votes come forward for discussion, the true condition of the Navy—a condition fraught with danger to the country—may be exposed in the House, by those naval officers and other critics who place the safety of their country before the convenience of party finance. That the condition of the Navy is serious will be abundantly evident to any one who takes the trouble to carefully study Mr. Trevelyan's speech. It is now perfectly clear that the shipbuilding policy of the present Board is dictated by precisely the same motives as was the policy of the late Conservative Board, as well as of the preceding Liberal Administration, a want of moral courage to come forward and tell the country the true condition of things, and to ask for the requisite funds to make the whole Navy really effective, because of the supposed unpopularity which increased estimates would entail.

The policy of the present Admiralty differs only in detail from that of its predecessors. When Mr. Ward Hunt came into power he found that the Liberal Administration before him had swelled their surpluses by allowing a large proportion of their ironclads to become ineffective from want of repairs to ships and boilers. During his administration, and that of his successor, Mr. W. H. Smith, this defect was remedied, so much so that Mr. Trevelyan tells us that we have now "actually 41 ironclads with their boilers in effective condition." But the Conservative Board failed in another and equally important duty. They found the task of maintaining the existing Navy to be so expensive, that they feared to ask the country for funds to build new ships as fast as they were required to keep pace with foreign rivals. Though they commenced many new vessels they finished but few. The Inflexible has been some six years under construction, and is not yet at sea, and of many other of their vessels it may safely be predicted that they will be out of date before they are completed. Even the Inflexible herself, the most powerful of our ships of the line, is known to be inferior in size, in armor, and in armament to the first-rate ironclads of two foreign navies. The present Board, having found the dockyards filled with partly-finished vessels, propose to complete them; but, on the other hand, they shelve altogether for the present the most important duty of commencing the construction of first-class ships of the line which shall be able to hold the seas against all comers. This deliberate omission will be severely felt in a year's time, when any ships now commenced should be ready for sea, and when we may confidently expect that the French and Italian navies will be even more formidable rivals than they are at present.

The actual new work which it is proposed to carry out during the coming year is as follows: The Agamemnon and Ajax are to be completed for sea at Chatham, and the Conqueror, an improvement on the Rupert, will be three-quarters finished. It is hoped also that the Polyphemus ram will be ready for sea by the end of the year. The sister ships, the Colossus and Majestic, building respectively at Portsmouth and Pembroke, are each to be advanced a fourth, and the Collingwood, which is described as the youngest device of the late Board, will have the first serious work done upon her. The late Board has now been out of office for a twelvemonth, and it is certainly a curious commentary on the energy of their successors that the first serious work on this ship should only now be in prospect. Not until the stress of these unfinished works is off his hands does the present First Lord intend to finally determine the type of the first-class ironclad of the future. Judging from past experience we may conclnde that another year will then elapse before he asks Parliament for funds to commence these ships. Delays will probably then arise, on account of some new necessity for the repair of the existing fleet; but granting that the new ships will not take longer to complete for sea than the Inflexible, viz., six years, a decade will nearly elapse before this country is in a position to meet the existing Italian ironclads.

Turning from the question of first-class ironclads to that of swift cruisers for the protection

of commerce, we find that at the present moment we have only eleven cruisers having a greater speed than 14 knots to protect one half of the entire mercantile marine of the world in case of war; and in this number are included the Mercury and Iris, which are, properly speaking, not cruisers at all, but swift despatch boats. The late Board attempted to improve this state of things by ordering the building of three fast cruisers, known as the Leander class. These three vessels are being built by private contract on the Clyde. The present Government intend to lay down a fourth Leander at Pembroke, but as this ship is only to occupy the spare time of the two hundred extra men at work on the ironclads, it will doubtless be some time before any serious work is commenced on her.

We now come to the most interesting proposal of the Government, viz., a class of cruiser which shall have a speed of 16 knots; a coal supply of 900 tons; auxiliary sail power; copper sheating, twin screws, and a belt of steel-faced armor 10 in. thick with 10 in. backing extending 140 ft. amidships, 3 ft. above water and 5 ft. below, so as to protect the boilers and machinery; also a steel conning tower, and an underwater deck, plated with 3 in. steel. covering the whole ship where not protected with side armor. The proposed length is 315 ft.; the extreme breadth 61 ft.; tonnage about 7,300, and engines of 8,000 horse power. The armament is to consist of four 18 ton 9.2 in. breech-loading guns of the new type, mounted *en barbette*, and six 6 in. breechloaders. In addition to the above, the vessels of the new type are to be provided with boat, field and machine guns, torpedoes, and probably with two torpedo boats. In the words of Mr. Trevelyan, she is intended to "rank high among cruisers, and high among second-class ironclads."

It is intended to lay down two such vessels this year at Government establishments, and later on to let out a third to contract. These vessels, if they at all combine the numerous advantages claimed for them, will undoubtedly be most useful additions to the fleet. The above list comprises all the principal features of the year's programme; but before quitting the subject, we must warn our readers not to be too sanguine that, modest as they are, these proposals will ever all be really carried into effect. The Board of Admiralty occasionally enliven their yearly statement by glowing promises to build cetain much-wanted ships for which they obtain the funds. The manœuver serves its purpose; it undoubtedly makes the programme of shipbuilding look effective, but sometimes it happens that the ships are not built. Sir E. J. Reed, a strong supporter of the Government, drew attention to this circumstance in language of impressive severity. It appears that, last year, the House was required to vote the funds for the construction of three new ironclads, to be laid down at the Chatham, Portmouth and Pembroke yards, and these have disappeared altogether from this year's programme. Thus, to use the words of Sir E. Reed, "the Government put ships into their programme, and took them out of it, at their pleasure, without consulting the House on the subject at all."

Another subject of the greatest importance is the arming of the fleet. We have it now admitted for the first time officially that our existing guns are obsolete. Mr. Trevelyan tells us that at the present moment there is not a single heavy breechloading gun mounted in any of our ships, but that by the end of next year a very substantial beginning would have been made towards arming the fleet with breech-loaders. In another place he states that the 18-ton guns of the new armored cruisers will be more powerful than the Woolwich guns mounted in the Thunderer, which, as is well known, weigh 38 tons. The ex-First Lord, Mr. Smith, makes the remarkable admission, that however good our Woolwich guns may be, there could be no doubt that the naval guns of England were inferior to the new guns on board the German, French and Russian ships, and that the Krupp gun was certainly superior to anything which we now possessed on board our fleet. Again, Mr. Stuart Rendel, whose practical acquaintance with the manufacture of heavy artillery cannot be disputed, tells us that, as far as armament was concerned, the whole British Navy might be considered to be at half power. These are serious admissions, but they fully bear out what we have ourselves in these pages unceasingly pointed out for the last ten years. It is with sincere pleasure that we acknowledge that the Government has at last arrived at a state of knowledge on this subject to which other people had attained years ago. Being, however, thus late in the day possessed of this information, it is little short of criminal folly to postpone for a single day longer than is absolutely necessary, the re-arming of our fleets and of our land defences. And we think that the Government can hardly be aware of its responsibilities, and of the duties which it owes to the country, when the representative of the Admiralty in the House of Commons calmly speaks of the end of next year, that is practically the commencement of the year 1883, as the period when a substantial *beginning* will have been made towards re-arming the fleet. We should like very much to know what guarantees the Government possesses that it will no. before that period arrives be called upon to confront the fleets of our neighbors with vessels which, on its own showing, are wholly armed with obsolete weapons, and which are therefore incompetent effectually to defend the country. Now that the truth is within their knowledge, the policy of the Admiralty in this respect must be pronounced as one which invites humiliation and which courts disaster.—*Engineering.*

TORPEDO VESSELS.—A paper on "The Further Development of the Thorneycroft Torpedo Vessels" was read, recently, at the Royal United Service Institution, by Mr. John Donaldson, M.I.C.E. When, four years ago, he delivered a lecture on the construction and armament of torpedo boats, Mr. Donaldson said he described the Scandinavian type of boat, the Dutch, Italian and French types, and

the *Lightning* type. These types had all gradually been developed into two distinct groups, comprising those attached to and carried by larger vessels, and those sufficiently large to act independently and to a certain extent to keep the sea. Having explained with the aid of diagrams the improvements which had been effected in the construction and fitting of boats of these two classes made by Messrs. Thorneycroft & Co. for our own and other Governments, he stated that the French had at present between 30 and 40 torpedo boats at Cherbourg alone, and an admirable system of training, under which most of the war marine were instructed in the use of torpedoes and torpedo boats. Looking forward, he suggested as improvements desirable in the larger or first-class torpedo boats, protection in front by means of 3-16 inch plates below deck and ¼-inch plate above deck in front of the conning tower, at such an angle as would prevent penetration at a distance of 400 to 1,000 yards; armament with machine guns and with the spar torpedo as in the case of the second-class boats, and a protection for the screw propeller.

THE ITALIAN MERCANTILE MARINE.—A correspondent writes: "The Italian parliament will shortly be asked to consider a project for uniting the two important steamship companies of Florio and Rubattino, so as to form one great Italian organization. The intervention of parliament would be merely formal, were it not that the law only allows the directors of such companies to remain two years in office, and the combined company will ask for a term of at least fifteen years. This long term is explained by a bill simultaneously presented to parliament by Signor Baccarini, the minister in connection with the intended fusion, authorizing a contract to be entered into by which, during fifteen years, the transport of 200,000 tons of coal from English to Italian ports would be given to an Italian company, which, on its part, would undertake to construct fifteeen large steamers. It is clear that the advantages already enjoyed by the Florio and Rubatino companies through the subsidies they receive for carrying the mails, would be considerably increased by the receipt of three and a-half million lire for the transport of those 200,000 tons of coal. It will be a blow to British shipping, which at present monopolizes the coal trade from England to Italy. Considering the advantages held out, it is very probable that the money will be found for the construction of the fifteen ships demanded. It remains to be seen, however, whether the free traders in the chamber of deputies, and they are not inconsiderable in number, will view the protection thus asked for Italian shipping favorably. Another question is whether the fifteen steamers, for the building of which the State would give an indirect subsidy, should be constructed abroad, or whether the company would undertake to have all or part built in Italy, and, if so, whether its dockyards have sufficient capacity for the work. Considering the great depression at present existing in the Italian mercantile marine, and the general readiness of the government to aid in its revival, the project may after all be favorably received, for it imposes on the company an addition to the Italian mercantile fleet of fifteen large steamers. Not having before me the exact tenor of the ministerial project, it is impossible to say in what manner the government will protect itself against the disadvantage of a fixed freight."

BOOK NOTICES.

PUBLICATIONS RECEIVED.

PRELIMINARY REPORT UPON THE IRON AND STEEL INDUSTRIES OF THE UNITED STATES. By James M. Swank. Philadelphia: American Iron and Steel Association.

CENSUS BULLETINS, 150 to 156, inclusive. Published by Department of the Interior, Washington.

TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS. RAIL PATTERNS. By A. L. Holley.

SPECIMEN MAPS FROM JOHNSTON'S ATLAS. Edinburgh: W. & A. K. Johnston.

ROORKEE HYDRAULIC EXPERIMENTS. By Captain Allan Cunningham, R. E. Vol. I.—Text. Vol. II.—Tables. Vol. III.—Atlas. Roorkee: Thomason College Press.

ANNUAL REPORT OF THE CHIEF ENGINEER OF THE WATER DEPARTMENT OF THE CITY OF PHILADELPHIA FOR 1880. By Wm. H. McFadden, Chief Engineer.

THE WORKSHOP. No. 6. PLATES No. 36—42. E. Steiger & Co.

PORTSMOUTH DOCKYARD EXTENSION WORKS. By Charles Colson, A. M. I. C. E., and Christian Hendrick Meyer, A. M. I. C. E. London: Published by Institution of Civil Engineers.

MODERN ARCHITECTURAL DETAILS. Part 9. New York: Bicknell & Comstock.

WORKING DRAWINGS; HOW TO MAKE AND HOW TO USE THEM. By Lewis M. Haupt, C. E. Philadelphia: Jos. M. Stoddardt & Co. For sale by D. Van Nostrand. Price,

In this little treatise the rudiments of descriptive geometry are presented in a manner that can readily be taught to pupils who are beginning mechanical drawing.

It is believed by the author, and with good reason, that the higher grades of our grammar schools can readily accomplish all that is comprised in this book. Moreover, when this short course is fairly mastered, the pupil will have sufficient knowledge of projections to construct working drawings of many objects, and he will have gone far towards the acquirement of a good practical knowledge of the various branches of draughting.

It is designed to follow this book with another for more advanced pupils.

COUR D'EXPLOITATION DES MINES. Per Amedee Burat. Paris: J. Baudry. For sale by D. Van Nostrand. Price,

This is the third edition of a well-known treatise. The text, including the supplement, extends over 736 royal octavo pages, while the plates fill a quarto atlas of 138 pages.

The topics treated are—General Methods of Working Mines; Working Coal Mines; Galleries and Tunnels; Draining and Ventilating; Compressed-Motors; Underground Transportation; Hoisting and Pumping Apparatus.

The supplement describes the improved methods of ventilating and hoisting and draining, as exhibited and worked in 1880.

The illustrations and text are excellent.

A PRACTICAL TREATISE ON THE MANUFACTURE OF STARCH, GLUCOSE, STARCH SUGAR AND DEXTRINE. From the German of Ladislaus von Wagner and other authorities. By Julius Frankel. Edited by Robert Hutter. Philadelphia: Henry Carey Baird & Co. For sale by D. Van Nostrand. Price,

The important industries indicated by the above title, seem to be treated with special reference to the practical side of the several topics. Beginning with the physical and chemical properties of starch, the author proceeds in a second section to describe, with great care, the processes of manufacture of starch from potatoes, wheat, corn and rice, each separately, and concludes with the methods of distinguishing the varieties and detecting adulterations.

Starch sugar is treated in similar manner. The history, terminology, physical and chemical properties cover nearly forty octavo pages. The various methods of manufacture forming the second section of "Part II.," constitute the more important portion of the work, and the detailed descriptions of the processes are proportionately expanded.

This section includes also the methods of testing, and the applications of the product.

Dextrine is the subject of Part III., and receives the same kind of treatment; the properties, manufacture, tests and uses being successively treated.

The illustrations throughout are of a good quality, and in quantity are all that the text requires.

A MILITARY DICTIONARY AND GAZETTEER. By Thomas Wilhelm, Captain of Infantry. Philadelphia: L. R. Hamersly & Co. For sale by D. Van Nostrand. Price,

The title of this work probably sufficiently explains its character, but its scope can only be fairly estimated from the schedule of its contents. It includes ancient and modern military technical terms, historical account of the different tribes of Indians, accounts of celebrated battles in all ages, and a concise explanation of all heraldic terms.

An appendix contains the articles of war.

MISCELLANEOUS.

TIMBUCTOO is only a collection of insignificant huts, and the great "basin" of the Sahara desert, which it was proposed to flood by the waters of the Mediterranean, and so make another inland sea, is no basin at all, but a plain, elevated considerably above the level of the Mediteranean. These are the revolutionary accounts brought back by Dr. Letz, a German traveler, just returned from a journey from Tangier to Timbuctoo.

ARTIFICAL SEASONING OF TIMBER.—To prepare timber for the sounding boards of musical instruments, so that they are not influenced by variations in temperature and atmospheric changes generally, Mr. C. Rene, pianoforte manufacturer of Stettin, Germany, has devised a plan by which he makes use of the property of oxygen, particularly of that ozonized by the electric current, to artificially season the timber. The first impulse to experiments being carried out in this direction was given by the well-known fact that wood, which has been seasoned for years, is much more suitable for the manufacture of musical instruments than if used soon after it is thoroughly dried only. Mr. Rene claims that instruments made of wood which has been treated by his oxygen process possess a remarkably fine tone, which not only does not decrease with age, but as far as experience teaches improves with age as does the tone of some famous old violins by Italian masters. We are further told that the sounding boards made of wood prepared in this manner have the quality of retaining the sound longer and more powerfully. A number of pianos manufactured at Mr. Rene's works, and exported to the tropics several years ago, have stood exceedingly well, and seem in no way affected by the climatic dangers they are exposed to. While other methods of impregnating wood with chemicals generally have a deteriorating influence on the wood fibers, timber prepared by this method, which is really an artificial ageing, becomes harder and stronger. The process is, we understand, regularly carried on at Mr. Rene's works, and the apparatus consists of a hermetically closed boiler or tank, in which the wood to be treated by the process is placed on iron gratings; in a retort, placed by the side of the boiler and connected to it by a pipe with stop valve, oxygen is developed and admitted into the boiler through the valve. Provision is made in the boiler to ozonize the oxygen by means of an electric current, and the boiler is then gently fired and kept hot for forty-eight or fifty hours, after which time the process of preservation of wood is complete.

LIGHTNING CONDUCTOR.—On the 6th instant, an interesting lecture was delivered at the Royal United Service Institution, by Captain James Bucknill, R.E., on the application of lightning conductors to buildings and magazines. The lecturer, with the assistance of capital diagrams, explained the action of thunder storms, and showed that they were least to be dreaded over non-conducting areas. He argued forcibly against any reliance being placed on the safe-circle theory, which has been revived of late both in this country and in France. Much was said in favor of iron

rather than copper for conductors, (*a*) because some samples of copper are so deficient in conducting power as compared with the best samples of copper, and iron being more constant in its conducting power; (*b*) because equal conducting power can be purchased in each for the same money, and there being a greater mass in the iron conductor, it is heated less by the same current of electricity; (*c*) because the fusing point of iron is much higher than that of copper; (*d*) because it is less liable to be stolen, or accidentally damaged. On the other hand, it was admitted that the small copper ropes and bands are less objectionable from an architectural view, because less observable It was urged that pliable wire ropes are better than bands, rods, pipes, &c., because the conductors can be continuous and without joints. For general purposes wire ropes weighing 6 lbs. per yard if of iron, and 1 lb. per yard if of good copper, were considered sufficient; and in the event of a conductor being carried up one side of a building along the roof and down the other side, a reduction of one-half in the conductivity was recommended if two good earth connections are provided. For a monument or spire, therefore, a 6-lb. iron-wire rope and one earth connection, and for a dwelling house a 3-lb. iron-wire rope and two earth connections, are recommended. Lofty rods were not advocated, but advantages were claimed for the multiple points. The very different amount of surface considered to be necessary by various authorities was stated, and this part of the subject was entered into very fully by the lecturer, some of whose arithmetical deductions were curious; especially those relating to the indifferent conducting power of water, as compared with the metals. The fact that the electrical resistance of copper and of water differ so greatly is brought home more thoroughly to our minds by the statement that a bar of water one yard long offers as much resistance as a copper bar of same diameter, and of a length equal to seven times the distance of the moon! Reasons were given for employing large earth connections, and for using coke or ashes as an enveloper and intermediary, their conducting power and low cost being such that they can be so used with very good effect. The lecturer, who was employed last summer in testing and inspecting a large number of the Government conductors on magazines, advocated that sliding joints should be discontinued, and that all joints, whether screwed, riveted, or otherwise, should, in addition, be soldered. Until this be done he stated his disbelief in the value of electric testing, but that with continuous conductors and properly constructed earth connections the electrical testing would at once become useful. An ingenious instrument was exhibited which had been designed by Captain Bucknill, for testing resistances not exceeding 11,000 ohms. The arrangement, which is very portable, combines a Wheatstone's balance, coils, galvanoscope, key, and terminals, with a small voltaic battery, which may or may not be added as desired. The whole forms an absolute testing arrangement, and the tests can be made quickly and without any difficulty. We propose, in a future number, to give a drawing and details of this apparatus, which is manufactured by Messrs, Elliott Brothers, Strand.

A NEW HIGH-SPEED MOTOR.—The Hon. R. C. Parsons has invented a new engine, which is manufactured by Messrs. Kitson & Co., of Leeds. Externally it consists of a closed cylindrical vessel, from one side of which the end of the crank shaft protrudes. The interior of the closed cylindrical vessel contains a steam engine having four single-acting cylinders arranged radially round the crank shaft, the center line of which is normal to the plane in which they lie. Mr. Parsons contents himself with a moderate speed for the reciprocating parts, viz., pistons and connecting rods. He does not allow for them a greater number of reciprocations than corresponds with, say, 450 revolutions per minute, and therefore keeps down the tendency to rattle, hammer, and disintegrate to a minimum. But he doubles the number of revolutions for the crank shaft by the simple expedient of causing the casting, forming the united four cylinders, also to rotate in the same direction as the shaft. Of course the casting referred to must be carefully balanced, but the radial arrangement makes this quite easy. And thus the high speed of 900 revolutions per minute is, it is claimed, attainable, and steadily maintainable, without noise, shake, undue wear and tear, or any known disadvantage beyond such as any other similar engine would be liable to when running at 450 revolutions. The object of the closed cylinder casing is obviously to collect the exhaust steam which clears itself away from the cylinders in succession the instant release takes place. It further serves the purpose of maintaining the temperature of the cylinders at at least 212°, and of enabling the exhaust steam, and any intermixed lubricants, to get at all enclosed moving parts. It also acts as a dust excluder and safety guard There is yet another new feature included in Mr. Parsons' engine. We have for some time become familiarized with the use of small pumps, attached to certain machines, for pumping oil or a soap and-water solution upon or under the cutting edge of a tool. The oil or solution afterwards flows away into a collecting reservoir, and is again utilized and re-utilized indefinitely. Mr. Parsons adopts this principle for lubricating the rapidly-revolving parts of his engine. He then makes sure of a continuous flow of oil at a sufficient pressure to keep apart the wearing surfaces, which ought, therefore, to remain cool and uninjured for any length of time, provided the small pump is kept in operation. The possible disadvantages which may attach to the new motor seem to us to be three fold, viz.: (1). It may prove to be heavy and expensive as to first cost, in proportion to power developed. There is obviously the cost of the cylindrical enclosing vessel, of the extra mechanism for rotating the cylinders, and of the oil-circulating machinery to provide On the other hand, double the power is gained by double the speed, and this will "cover a multitude of

sins." To credit there is also the bed plate and supports of some kind, which, but for the casing, would be necessary. (2). Like all single-acting engines, the pistons are working during half only of each revolution. This means extra weight and original cost per foot-pound of power developed, as compared with double-acting cylinders. (3). It cannot be an economical engine if the pistons be made to act inwards, because that would manifestly involve the usual long steam passages to convey the steam for the central distributing valve to the outer ends of the cylinders. The large obnoxious spaces thereby formed prevent all chance of economy. It is, however, not clear whether the steam may not now or might not possibly be made to act outwards in connection with the large surrounding exhaust chamber, and whether in such case large obnoxious spaces may not be used. It is understood that Messrs. Kitson & Co. are manufacturing this motor for Mr. Parsons, and that modifications have already been designed for other purposes as well as for driving dynamo-electric machines.—*Engineer.*

THE DECIMAL SYSTEM.—When Mr Ashton Dilke rose in his place in the House of Commons, on Tuesday night, to move "That in the opinion of this House the introduction of a decimal system of coinage, weights and measures, ought not to be longer delayed," he did so probably with a full sense of the opposition which this proposed change is sure to meet. The plausible way in which he supported his proposal, and the arguments which he used, have been tried before upon the British public, hitherto without success. That public, as represented in the House of Commons, in a kind of panic, have done many wise and many foolish things, but many useful measures and reforms have been carried and effected only after the most persevering efforts by their authors. Notwithstanding the official discountenance which Mr. Dilke's motion experienced, that gentleman may rest assured that the reform which he advocates is one which must, sooner or later, be adopted. It has the cordial support of the great majority of the scientific portion of the community. It is to be regretted that this country should, in this respect, be behind other nations who have changed their systems, but the very decided advantages which so simple a means of reckoning presents constitute an argument for its introduction which it is difficult to meet, and which will one day convince even so stubborn an animal as John Bull.

THE SUEZ CANAL.—There have been loud complaints on the part of shipowners regarding the general management of the Suez Canal, and especially the system of piloting vessels. Thus, in one case, it is stated that a certain vessel could only get a pilot who, not knowing any English, was necessarily unable to give intelligible orders. Hence, four days were consumed in getting from Ismaila to Port Said, the ship having grounded several times, and also got into collision with a steamer. What makes the case worse is, that pilot dues on the canal seem to be decidedly liberal, being £26 a day for the ordinary passage of forty-eight hours. These payments, however, are applied, it is stated, in great part to cover other contingent expenses. Another charge, amounting to £21, in the case of a vessel of 1211 tons, on the score of light dues, seems to be at all events extravagant; but any excess in this item is, it appears, the unearned perquisite of the Egyptian government. All this, in the case of a vessel of the size named, is in addition to the heavy tolls, amounting to £650. Inquiry into these matters would be highly desirable, especially as the undertaking has an international character, and in which this country has by far the largest interest. We gave, a short time ago, some approximate figgures of the traffic that has passed through the canal in the past year. From official statistics now published, it appears that, in the course of 1880, 2017 ships passed through the canal, with a tonnage, according to official reckoning, of 2,860,448, but really amounting to 4,378,964 tons. The number of hands employed in the navigation was 128,453, the number of passengers 53,517. Of the 2,860,448 tons, official reckoning, 2,247,306 were British, 177,771 French, 75,820 Austrian, 124,083 Dutch, 71,039 Italian, 56,245 Spanish, 38,162 German, 29,607 Russian, 7,203 Turkish, 8,032 Egyptian, while 25,180 tons belonged to other countries.

AN ELECTRIC LETTER POST.—Improving upon the electric railway, Dr. Brunner von Wattenwyl has invented a similar railway by which, he believes, letters may be transmitted to great distances, as they are now sent to short distances in pneumatic tubes. Messrs. Siemens and Halske, of Berlin, have constructed a model of the inventor's apparatus, which was exhibited last week at the lecture which Herr von Wattenwyl delivered before the Scientific Club of Vienna. The lecturer proposes to place miniature lines of railway near or under the great railway lines, and to put these into communication with small electric locomotives, to which would be attached small wagons to take up letters. The letter post would run with more than railway speed, and would have the advantage of being independent of trains, and capable of being used at any time. The electric letter post exhibited during the delivery of the lecture was made to proceed along the rails at any speed required. The lecturer, after referring to the doctrine of the correlation of forces and its connection with his invention, pointed out that one of the chief advantages of the new power was that it was worked from the railway stations, and was not carried along the line by locomotives. It remains to be seen whether the invention is of such a nature as to enable it being put into practical operation.